Science Requirements Envelope Document Compliance Matrix

Fluids and Combustion Facility Project

Rev. C
Final
January 9, 2001

AUTHORIZED by CM when under FORMAL Configuration Control	
Date	**Signature**
01/12/01	*/s/ Robert H. Van Niel*

Prepared For:
National Aeronautics and Space Administration
John H. Glenn Research Center
Microgravity Science Division
Cleveland, Ohio 44135

FDC
FEDERAL DATA CORPORATION

Prepared By:
Federal Data Corporation
Under Contract NAS3-99155
2001 Aerospace Parkway
Brook Park, Ohio 44142

PREFACE

The National Aeronautics and Space Administration (NASA) is developing a modular, multi-user experimentation facility for conducting fluid physics and combustion science experiments in the microgravity environment of the International Space Station (ISS). This facility, called the Fluids and Combustion Facility (FCF), consists of three test platforms: the Fluids Integrated Rack (FIR), the Combustion Integrated Rack (CIR), and the Shared Accommodations Rack (SAR). This document has been developed to show compliance with the requirements for the three rack facility, as specified in FCF-DOC-002, FCF Science Requirements Envelope Document.

REVISION PAGE
Science Requirements Envelope Document Compliance Matrix

Revision	Date	Description of Change or ECOs/ECPs Incorporated	Verification and Date
B	10/26/00	Preliminary - Submitted for review for FCF PDR	10/27/00
C	01/09/01	Final - Revised in accordance with customer comments for PDR. Previous revision dated 10/26/00 was incorrectly identified as Revision A.	01/12/01

SCIENCE REQUIREMENTS ENVELOPE DOCUMENT COMPLIANCE MATRIX FOR THE FLUIDS AND COMBUSTION FACILITY PROJECT

Prepared By:

/s/ Geet Varghese for JJM **Date:** *01/12/01*
J. John Merry
FIR Systems Lead
Federal Data Corporation

/s/ James McDade IV **Date:** *01/12/01*
James McDade IV
FIR Lead Optical Engineer
Federal Data Corporation

/s/ Stephen J. Lawn **Date:** *01/12/01*
Stephen J. Lawn
CIR Optical Engineer
Analex Corporation

/s/ Mark W. Pestak **Date:** *01/12/01*
Mark W. Pestak
Science Liason
Federal Data Corporation

Approved By:

/s/ Nora Bozzolo **Date:** *01/12/01*
Nora G. Bozzolo
FCF Common Equipment Manager
Analex Corporation

/s/ William F. Quinn **Date:** *01/12/01*
William F. Quinn
Product Assurance and Safety
Hernandez Engineering Inc.

/s/ Jon C. Wetherholt **Date:** *01/12/01*
Jon C. Wetherholt
FCF Systems Engineering Manager
Analex Corporation

/s/ Andrew M. Peddie **Date:** *01/12/01*
Andrew M. Peddie
FCF Deputy Director
Federal Data Corporation

/s/ Andrew M. Peddie for CJP **Date:** *01/12/01*
Christopher J. Pestak
FCF Program Director
Analex Corporation

FEDERAL DATA CORPORATION
Federal Data Corporation
2001 Aerospace Parkway
Brook Park, Ohio 44142

Chapter 1 - Introduction

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1 CM INTRODUCTION

This section describes the purpose, scope, and format of this *Compliance Matrix* (CM) document. It also explains the relationship between this and other key FCF Project documents.

1.1 CM PURPOSE

The CM is a checklist. Each page in the CM identifies a single science requirement, desired feature/goal from the SRED. Further definition can be found in the BCD.

The CM is used to explain FCF compliance and identify disconnects between requirement and response.

1.2 CM SCOPE

The CM covers the entire FCF system for its entire life cycle. The life cycle extends to ultimate decommissioning and disposal.

This document shall be baselined as part of the Preliminary Design Review (PDR). It shall be updated regularly to summarize FCF design versus Science requirements.

1.3 CM FORMAT

The CM is a simple checklist. Each page lists an abbreviated statement of the requirement, or desired feature/goal (denoted by a "D" preceding the number (i.e. DO3). The actual requirement – desirement verbiage within this Compliance Matrix originates from the SRED, Appendix D. The original SRED section is referenced next to the requirement. Below each requirement is an engineering interpretation and response. Further clarification of how the requirements are met can be found in the appropriate section of the BSD.

Note: The brief statement of requirements is not the full statement of the requirements. One cannot fully understand either the requirement of the response without reading the appropriate SRED and BSD sections. Again, the CM is only a checklist.

1.4 CM RELATIONSHIP TO OTHER DOCUMENTS

This section describes the relationships among key FCF documents.

1.4.1 Science Requirements Envelope Document

The *FCF Science Requirements Envelope Document* (SRED) contains the scientific requirements placed on FCF. FCF must meet these requirements within limits imposed by the technology state-of-the-art, ISS resource constraints, NASA funding constraints, and other relevant constraints. This document also serves a Microgravity Program function because all parties and organizations involved with FCF implementation agree to implement the requirements (i.e. it is a form of contract).

1.4.2 Baseline Concept Description

The *Baseline Concept Description* (BCD) document provides a description of the International Space Station (ISS) Fluids and Combustion Facility (FCF) system in an easily understood format of illustration and narrative. All the team members working on the project as a communication tool use it, and it is used for briefings, studies, and cost estimates.

The FCF system described in the BCD is a response to the requirements stated in the *FCF Science Requirements Envelope Document* (SRED) and to other requirements and constraints (e.g. ISS resource constraints).

1.4.3 Baseline System Description

The BCD evolves into the *Baseline System Description* (BSD) document by FCF PDR. Afterward the BCD is 'retired' and the BSD serves the BCD purpose per 1.4.2.

1.4.4 Compliance Document

The *Compliance Matrix* (CM) is a 'check list' that indicates the correspondence between requirements in the SRED and engineering features in the BCD. It is used to assure that requirements have been captured by the FCF design.

1.4.5 Project Plan

The *FCF Project Plan* (PP) describes the management principals, work breakdown structure, schedule, and budget needed to implement FCF as described in the BCD. It is a contract between the Project and the Program.

1.4.6 Science Requirements Document

The individual Principal Investigators (PIs) whose experiments are accepted for FCF will write the Science Requirements Documents (SRD). The SRDs place a subset of the SRED requirements on FCF unique to each experiment and also describe special hardware that may be needed to customize FCF for each experiment. This document assures that the PIs will get what they need.

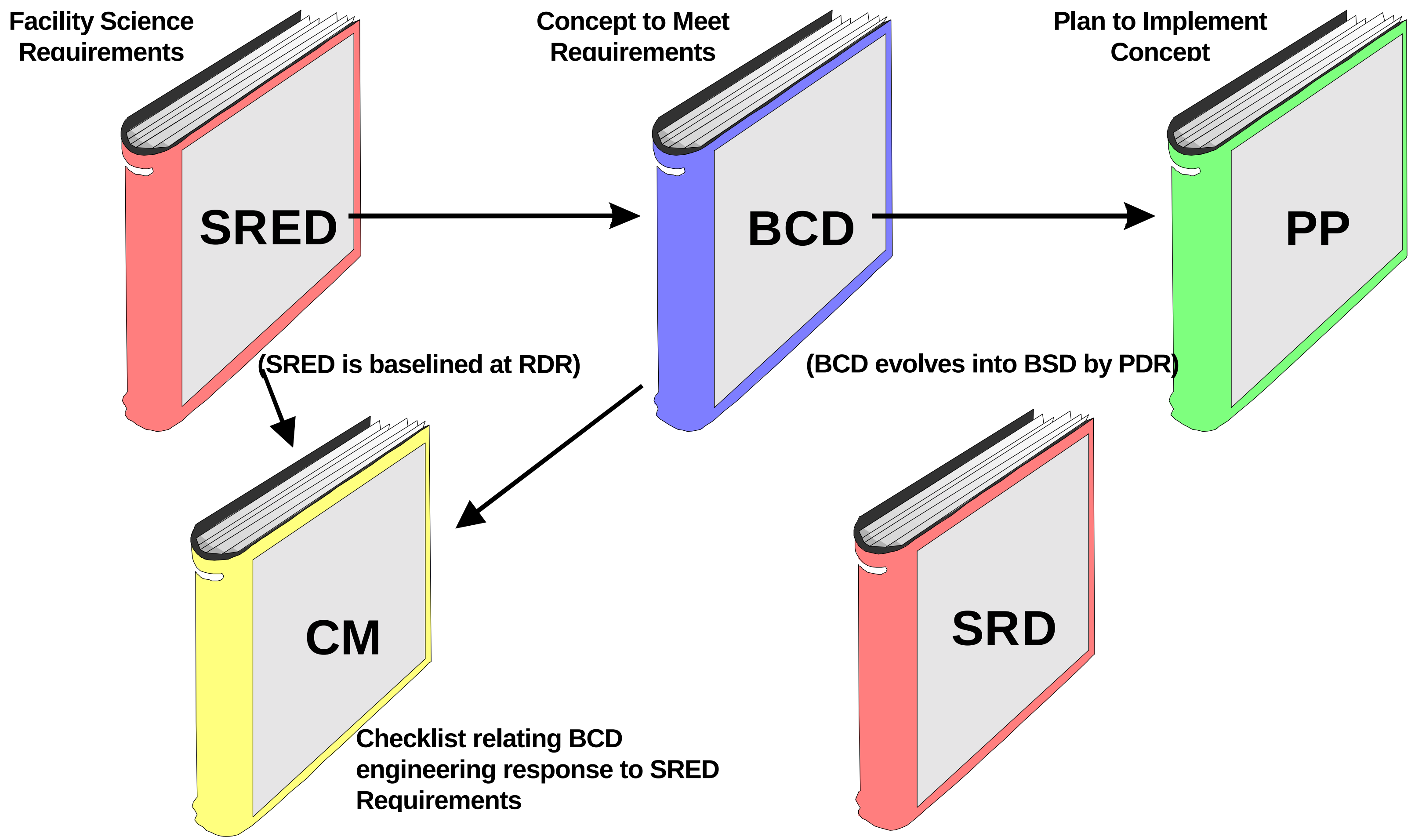
1.4.7 Document References

References are made in this document in abbreviated format to other FCF Project Documents. These referenced documents are as follows:

SRED	FCF-DOC-002
FCF A-Spec	FCF-SPC-0001
FCF BSD	FCF-DOC-0003
FIR B-Spec	FCF-SPC-0003
CIR B-Spec	FCF-SPC-0002

The facing figure illustrates the relationships among the SRED, BCD, CM, PP, and SRD.

Relationship Among FCF Project Documents



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Chapter 2 - Science Requirements

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SRED REQUIREMENT Req. P1 - The Fluids and Combustion Facility (FCF) shall be a permanent on-orbit research facility located inside the United States Laboratory Module (US Lab) of the International Space Station (ISS). FCF shall support NASA Human Exploration and Development of Space (HEDS) Microgravity Program objectives. In particular, FCF shall accommodate and facilitate sustained, systematic Microgravity Fluid Physics and Microgravity Combustion Science experimentation on the ISS for the lifetime of the ISS.	SRED Sec. 1.2.1
ENGINEERING INTERPRETATION The FCF must be a permanent on-orbit research facility located in the United States Laboratory Module of the International Space Station (i.e., no rack change-out). It must support sustained, systematic Microgravity Fluid Physics and Combustion Science experimentation on ISS for the (10 year) lifetime of ISS.	FCF A-Spec Sec. 1.2
ENGINEERING RESPONSE COMPLY The FCF system is comprised of a permanent, modular, multi-user facility and ground equipment whose primary purpose is to perform microgravity research in the disciplines of fluid physics and combustion science on board the United States Laboratory (USL) Module of the International Space Station. FCF will be installed in contiguous rack locations in the US Laboratory and support the accomplishment of NASA Human Exploration and Development of Space (HEDS) Program objectives requiring sustained, systematic microgravity research on the Space Station in both of these science disciplines. The FCF system is being designed for an operational lifetime of 10 years from the point of full deployment on ISS. Due to the modular architecture of the facility, this operational life will be extendible to 15 years without having to return a rack to Earth, provided additional upmass, volume and crew time are available to FCF for maintenance and servicing during the 5 year extension period.	BSD Ch. 1

SRED REQUIREMENT Req. P2 - Fluid Physics and Combustion Science shall be of equal relative priority within the scope of FCF planning, design, operations, and other activities.	SRED Sec. 1.2.1
ENGINEERING INTERPRETATION The fluid physics and combustion science disciplines must be of equal relative priority within the scope of the FCF design, planning, operations and utilization on ISS.	FCF A-Spec
ENGINEERING RESPONSE COMPLY The ISS Fluids and Combustion Facility (FCF) is being designed to provide a common on-orbit infrastructure that will be used by both the microgravity fluid physics and the microgravity combustion science disciplines. When fully deployed on the Space Station, the FCF flight segment will consist of three racks. The Combustion Element/CIR will primarily support the microgravity combustion science discipline. The Fluids Element/FIR will primarily support the microgravity fluid physics research discipline. Shared accommodations in the central FCF rack will provide shared on-orbit equipment, volume, and capability to support both research disciplines. Though the rack launch sequence of the FCF (CIR first, followed by FIR, then SAR) will allow initial operational capability (IOC) for combustion science on ISS before fluid physics IOC, the effect of this approach will not significantly favor either discipline over the 10+ years of microgravity combustion and fluid physics research in FCF on the Space Station.	BSD Sec. 4

SRED REQUIREMENT Req. P3 - FCF shall plan to occupy no more than 3 International Standard Payload Racks (ISPR) located in the US Lab module plus up to 1 additional rack of unpowered stowage, as needed to meet the Level 1 requirements.	SRED Sec. 1.2.1
ENGINEERING INTERPRETATION FCF shall occupy no more that 3 ISPRs in the US Laboratory. FCF shall not require more than 1 additional rack of un-powered stowage in ISS (not including fluids/combustion PI equipment) to meet the FCF Level 1 science requirements.	FCF A-Spec Sec. 3.1.1.3
ENGINEERING RESPONSE COMPLY The FCF CIR will occupy one rack in the US Lab. The FCF FIR will occupy a second rack in the US Lab. When fully deployed on ISS (i.e., with SAR added), the FCF will occupy three racks in the US Laboratory. These racks must be in contiguous locations with the SAR as the central FCF rack. The designated locations of these racks in the US Lab are as follows: CIR-LAS2, SAR-LAS3, and FIR-LAS4. These three FCF racks are being designed to support the required PI throughput and science utilization in both the combustion research disciplines within expected resource allocations that will be available on the Space Station. On-orbit stowage will be provided on ISS for FCF. FCF analysis of transportation and stowage requirements for the Combustion Integrated Rack (CIR) indicates that one rack or less of on-orbit stowage will be sufficient to meet the Level 1 requirements.	BSD Sec. TBD, and FCF A-Spec Sec. 3.2.2.1

SRED REQUIREMENT Req. P4 - FCF Level 1 requirements shall take precedence over other scientific and technical requirements.	SRED Sec. 1.2.1
ENGINEERING INTERPRETATION The level 1 requirements stated in the SRED take precedence over all other scientific requirements stated in the SRED, PI-specific science requirements and any other technical requirements which that define the FCF system.	FCF A-Spec
ENGINEERING RESPONSE COMPLY The Science Requirements Envelope Document (SRED) states the highest level Microgravity Science Program performance requirements, as well as the Fluid Physics and Combustion Scientific requirements that control the development, deployment and operation of the Space Station Fluids and Combustion Facility, with the exception of safety requirements, which take precedence over all requirements. No disconnects have been identified.	BSD

SRED REQUIREMENT Req. P5 - After ISS and FCF assembly complete, FCF shall permit a utilization rate of at least 5 Basis Experiment type fluid physics experiments per year while remaining within budgetary and technical constraints as understood in 1998; however, FCF shall be designed to support a utilization rate of 10 fluid physics experiments per year, should resources permit. FCF compliance to this requirement shall be shown by an analysis indicating that a majority of Fluid Physics Basis Experiments could be flown on FCF at a rate of 5 per year within budgetary and ISS resource constraints.	SRED Sec. 1.2.2
ENGINEERING INTERPRETATION After ISS and FCF assembly complete, the FCF shall permit a utilization rate of at least 5 Basis-type fluid physics experiments per year while remaining within budgetary and technical constraints. However, FCF shall be designed to support a utilization rate of 10 fluid physics experiments per year, should resources permit.	FCF A-Spec Sec. 3.2.2.3
ENGINEERING RESPONSE COMPLY The Fluids and Combustion Facility must support 10 typical PI-specific investigations per year (e.g., 5 fluids experiments per year), assuming no failures, within the following design resource constraints: Power – 2000W; Energy – 9000 kW-hr/yr.; Thermal Cooling Water – 90 kg/hr; Crew time – 145 hr/yr.; A/G communications 20 Mbits/sec, 20x10E9 Bytes/day. The FCF design incorporates a number of resource conservation measures for key ISS resources such as crew time, upmass, volume, power, cooling water, and cost, which will allow the facility to meet PI throughput requirements. FCF functions that do not necessarily require crew action, such as facility operation, will be automated or allocated to ground operations to the greatest extent possible to minimize crew time requirements. Maintenance times will also be minimized by the incorporation of redundancy and hardware designs that maximize maintainability. The flexibility of the FCF architecture will allow upgrades to hardware as science requires and as technology becomes available that may enhance the scientific productivity of the facility. The FCF electrical power subsystem has been designed to reduce the margin required for operations by providing the ability to draw power simultaneously from both ISS power buses as the need arises and the ability to shed FCF loads to ensure that the FCF stays within its power resource allocations. Reaching 10 fluids experiments per year presents difficulties in scheduling ground segment resources; the difficulties are mitigated by the presence of the SAR. Experiment throughput analysis indicates that 5 typical fluids physics experiments per year can be accommodated by the FCF. Reference document FCF-ANA-0109. However, certain basis experiments have resource demands that, as currently defined, will not allow a throughput rate of 5 fluids experiments per year.	BSD

SRED REQUIREMENT Req. P6 - After ISS and FCF assembly complete, FCF shall accommodate at least 80 percent of the microgravity fluid physics experiments likely to be proposed for ISS. FCF compliance shall be shown by conceptual experiment layouts and analysis indicating that 80 percent of the Fluid Physics Basis Experiments could be accommodated by FCF facility capabilities when augmented by PI hardware capabilities.	SRED Sec. 1.2.2
ENGINEERING INTERPRETATION After ISS and FCF assembly complete, FCF shall accommodate at least 80 percent of the microgravity fluid physics experiments likely to be proposed for ISS. 80% of the fluid physics Basis Experiments could be accommodated by FCF facility capabilities when augmented by PI hardware capabilities.	FCF A-Spec Sec. 3.2.2.3
ENGINEERING RESPONSE COMPLY Conceptual experiment layouts and analysis have been performed by PDR to demonstrate that at least 80% of the fluid physics Basis-type Experiments can be accommodated by the FCF facility capabilities. The FIR Basis Experiments Compliance Matrix Appendix B in this document provides a preliminary assessment of compliance with the 16 fluid physics Basis-type Experiments. FCF and PI-provided items allow for 94% compliance to the envelope of science requirements for the fluids experiments that are currently defined. 15 of 16 Basis Experiments are successfully accommodated in the FIR.	BSD

SRED REQUIREMENT	SRED Sec.
Req. P7 - To accommodate potential commercial and international users, FCF shall accommodate at least 5 additional (in addition to Req. P5) fluid physics experiments per year, assuming that PI hardware and resources are provided by those users.	1.2.2
ENGINEERING INTERPRETATION The FCF must accommodate potential commercial and international users (at least 5 additional users per year) beyond Requirement P5 that states that FCF must be capable of accommodating 5-10 fluid physics experiments per year. This implies that FCF must be capable of accommodating up to a total of 15 fluid physics basis-type experiments per year. This assumes that commercial and international users provide ISS resources and PI hardware.	FCF A-Spec Sec. 3.1.1, 3.2.2.3
ENGINEERING RESPONSE COMPLY An analysis has been performed to show what PI throughput may be achieved as a function of resources that are available. At this time, FCF believes that there are no limiting features in the FCF system architecture that will preclude this requirement from being met, providing that the additional experiments fall within the SRED envelope. The modular design of the FCF allows it to accommodate additional commercial and international experimenters.	BSD

SRED REQUIREMENT Req. P8 - After ISS and FCF assembly complete, FCF shall permit a utilization rate of at least 5 Basis Experiment type combustion science experiments per year while remaining within budgetary and technical constraints as understood in 1998; however, FCF shall be designed to support a utilization rate of 10 combustion science experiments per year, should resources permit. FCF compliance to this requirement shall be shown by an analysis indicating that a majority of Combustion Science Basis Experiments could be flown on FCF at a rate of 5 per year within budgetary and ISS resource constraints.	SRED Sec. 1.2.3
ENGINEERING INTERPRETATION After ISS and FCF assembly complete, the FCF shall permit a utilization rate of at least 5 Basis-type combustion experiments per year while remaining within budgetary and technical constraints. However, FCF shall be designed to support a utilization rate of 10 combustion experiments per year, should resources permit.	FCF A-Spec Sec. 3.2.3.3
ENGINEERING RESPONSE COMPLY The Fluids and Combustion Facility must support 10 typical PI-specific investigations per year (e.g., 5 fluids experiments and 5 combustion experiments, per year), assuming no failures, within the following design resource constraints: Power – 2000W; Energy – 9000 kW-hr/yr.; Thermal Cooling Water – 90 kg/hr; Crew time – 145 hr/yr.; A/G communications 20 Mbits/sec, 20x10E9 Bytes/day. The FCF design incorporates a number of resource conservation measures for key ISS resources such as crew time, upmass, volume, power, cooling water and cost, which will allow the facility to meet PI throughput requirements. FCF functions that do not necessarily require crew action, such as facility operation, will be automated or allocated to ground operations to the greatest extent possible to minimize crew time requirements. Maintenance times will also be minimized by the incorporation of redundancy and hardware designs that maximize maintainability. The flexibility of the FCF architecture will allow upgrades to hardware as science requires and as technology becomes available that may enhance the scientific productivity of the facility. The FCF electrical power subsystem has been designed to reduce the margin required for operations by providing the ability to draw power simultaneously from both ISS power buses as the need arises and the ability to shed FCF loads to ensure that the FCF stays within its power resource allocations. Reaching 10 combustion experiments per year presents difficulties in scheduling ground segment resources; the difficulties are mitigated by the presence of the SAR. Experiment throughput analysis indicates that 5 combustion experiments per year can be accommodated by the FCF. Reference document FCF-ANA-0109. However, one combustion basis experiment has resource demands that, as currently defined, will not allow a throughput rate of 5 combustion experiments per year.	BSD

SRED REQUIREMENT Req. P9 - After ISS and FCF assembly complete, FCF shall accommodate at least 80 percent of the microgravity combustion science experiments likely to be proposed for ISS. FCF compliance shall be shown by conceptual experiment layouts and analysis indicating that 80 percent of the Combustion Science Basis Experiments could be accommodated by FCF facility capabilities when augmented by PI hardware capabilities.	SRED Sec. 1.2.3
ENGINEERING INTERPRETATION After ISS and FCF assembly complete, FCF shall accommodate at least 80 percent of the microgravity combustion experiments likely to be proposed for ISS. 80% of the combustion Basis Experiments could be accommodated by FCF facility capabilities when augmented by PI hardware capabilities.	FCF A-Spec Sec. 3.2.2.3
ENGINEERING RESPONSE COMPLY Conceptual experiment layouts and analysis have been performed to demonstrate that at least 80% of the combustion Basis-type Experiments can be accommodated by the FCF facility capabilities. The CIR Basis Experiments Compliance Matrix appendix in this document provides a preliminary assessment of compliance with the 11 combustion Basis-type Experiments. However, FCF and PI-provided items allow for 99% compliance to the envelope of science requirements for the combustion experiments that are currently defined (Basis and actual).	BSD

SRED REQUIREMENT Req. P10 - To accommodate potential commercial and international users, FCF shall accommodate at least 5 additional (in addition to Req. P8) combustion science experiments per year, assuming that PI hardware and resources are provided by those users.	SRED Sec. 1.2.3
ENGINEERING INTERPRETATION The FCF must accommodate potential commercial and international users (at least 5 additional users per year) beyond Requirement P5 that states that FCF must be capable of accommodating 5-10 combustion experiments per year. This implies that FCF must be capable of accommodating up to a total of 15 combustion basis-type experiments per year. This assumes that ISS resources and PI hardware are provided by commercial and international users.	FCF A-Spec Sec. 3.2.2.3
ENGINEERING RESPONSE COMPLY An analysis has been performed to show what PI throughput may be achieved as a function of resources that are available. At this time, FCF believes that there are no limiting features in the FCF system architecture that will preclude this requirement from being met. Based on results of a scheduling simulation, full compliance requires both the CIR and the SAR to be on-orbit because not all the required functionality can be placed in the CIR alone. Furthermore, use of the SAR for certain functions saves on-orbit power, energy, cooling, and Astronaut hours as needed to meet the requirement within the resource allocations. Reaching 10 combustion experiments per year presents difficulties in scheduling ground segment resources; the difficulties are mitigated by the presence of the SAR. Adding 5 more combustion science experiments (total 15 per year) per this requirement will require additional ground facilities versus the current plan, providing that the additional experiments fall within the SRED envelope. The modular design of the FCF allows it to accommodate additional commercial and international experimenters.	BSD

SRED REQUIREMENT Req. P11 - The Fluid Physics Basis Experiments shall be precisely the 14 experiments listed in Table P11.	SRED Sec. 1.3.2
ENGINEERING INTERPRETATION The FCF must be designed to conduct the 16 fluid physics basis experiments listed in Table P11	FCF A-Spec Sec. 3.2.2.3
ENGINEERING RESPONSE COMPLY The FCF is being designed to accommodate the following fluid physics basis-type experiments: 1) thin film flows at menisci, 2) contact line hydrodynamics, 3) rheology of non-newtonian fluids, 4) dynamics of hard sphere colloids, 5) colloid physics, 6) studies in electrohydrodynamics, 7) nucleation and growth of microporous crystals, 8) interactions of bubbles and drops, 9) thermocapillary motion of bubbles and drops, 10) interfacial transport and micellar solubilization, 11) thermocapillary and double diffusive phenomena, 12) critical point phenomena, 13) multiphase flow boiling and 14) mechanics of granular media 15) shear rheology of complex fluids, and 16 mesoscopic studies of colloids and complex fluids. These 16 basis-type experiments cover the following areas of research; thermocapillarity, fluid rheology, colloids, first order phase transitions, electrohydrodynamics, diffusive phenomena, second order phase transitions, multiphase flow and granular media. These 16 fluids experiments were the basis experiments that were used to develop the FCF system.	BSD

SRED REQUIREMENT Req. P12 - The Combustion Science Basis Experiments shall be the 11 experiments listed in table P12.	SRED Sec. 1.3.3
ENGINEERING INTERPRETATION The FCF must be designed to conduct the 11 combustion basis experiments listed in Table P12.	FCF A-Spec Sec. 3.2.2.3
ENGINEERING RESPONSE COMPLY The FCF is being designed to accommodate the following combustion basis-type experiments: 1) gas jet diffusion flames, 2) structure of flame balls at low Lewis numbers, 3) Ignition and Flame Spread Over Liquid Fuel Pools, 4) Diffusive and Radiative Transport in Fires, 5) Smoldering Combustion, 6) Droplet Combustion, 7) Laminar Soot Processes, 8) Soot Measurement in Droplet Combustion, 9) Unsteady Burning of Contained Reagents, 10) Solid Fuels Flammability Boundary and 11) Radiative Ignition and Transition in Flame Spread. These 11 basis-type experiments cover the following areas of combustion research; laminar flames, turbulent combustion, reaction kinetics, condensed phase organic fuel combustion, flame spread and fire suppressants, condensed phase organic fuel combustion, droplet spray combustion, soot and polycyclic aromatic hydrocarbons. These 11 combustion experiments were the basis experiments that were used to develop the FCF system.	BSD

SRED REQUIREMENT Req. P13 - The FCF Science Requirements Envelope Document (SRED) shall present Basis Experiment requirements collectively.	SRED Sec. 1.3.4
ENGINEERING INTERPRETATION Similar requirements (obtained from individual basis experiments) shall be grouped by type and shall be presented collectively without emphasizing individual requirements from individual Basis Experiments.	FCF A-Spec
ENGINEERING RESPONSE COMPLY This is a requirement levied upon the authors of the SRED. The SRED does comply with this requirement. An engineering response related to the FCF concept is not applicable here.	BSD

SRED REQUIREMENT Req. P14 - When considering requirements of a given type collectively, the FCF developer may elect to de-emphasize requirements that represent extreme cases relative to the rest of the collection. An extreme case is a requirement that serves less than two Basis Experiments and lies at the edge of the envelope. The intent of this requirement is in keeping with P6 and P9.	SRED Sec. 1.3.4
ENGINEERING INTERPRETATION The FCF developer may elect to de-emphasize requirements that represent extreme cases relative to the rest of the collection when considering requirements of a given type collectively.	FCF A-Spec
ENGINEERING RESPONSE COMPLY This is understood and in keeping with the requirement that FCF shall accommodate at least 80 percent of the microgravity combustion experiments and 80 percent of microgravity fluid physics experiments likely to be proposed for ISS. However, the FCF is being developed to consider the total breadth of requirements from the SRED and from the actual experiments.	BSD

SRED REQUIREMENT Req. P15 - The FCF project's highest priority shall be to meet Requirements followed by implementing Desired Capabilities. Suggestions shall have no implementation priority; however, they should be seriously considered while making trade-off decisions.	SRED Sec. 1.3.4
ENGINEERING INTERPRETATION FCF must meet all requirements in the SRED. Desired capabilities will be incorporated to the extent possible, in keeping with cost, technical, schedule and other constraints on the development.	FCF A-Spec Sec. 3.2.2.3
ENGINEERING RESPONSE COMPLY The relative priority of requirements, desired capabilities and suggestions in the SRED is understood. The FCF is being designed to meet the requirements. The design effort will incorporate desired capabilities to the maximum extent possible.	BSD Sec. TBD, FCF A-Spec, and lower-level specs.

SRED REQUIREMENT	SRED Sec.
Req. P16 - To be an FCF science requirement an item shall meet the following minimum criteria: 1. The requirement shall be stated as (or be interpretable as) a functional capability. Examples: a requirement could be stated as an ability to measure a given parameter with a given accuracy, or a requirement could be stated as a capability to provide laser lighting at certain wavelengths and power levels. 2. At least one Basis Experiment will fail if the requirement is not met. The burden of proof regarding this criterion is on the person or group proposing the requirement. 3. Inspection, analysis, or test can objectively verify how well FCF meets the requirement. An acceptable verification method can be suggested as part of the requirement; however, the FCF developer may elect to use a different verification method.	1.3.4.1
ENGINEERING INTERPRETATION Science requirements must meet the listed criteria to be an FCF science requirement.	FCF A-Spec
ENGINEERING RESPONSE COMPLY This is a requirement levied upon the authors of the SRED. An engineering response is not required.	BSD

SRED REQUIREMENT Req. P17 - To be a valid FCF desired capability or feature an item shall meet the following minimum criteria: 1. Does not qualify as a requirement. 2. Supported by objective data indicating that at least two Basis Experiments would have substantially greater scientific yield if the desired capability were implemented. The burden of proof regarding this criterion is on the person or group proposing the capability or feature. 3. Inspection, analysis, or test can objectively verify how well FCF provides a capability. An acceptable verification method can be suggested; however, the FCF developer may elect to use a different verification method.	SRED Sec. 1.3.4.2
ENGINEERING INTERPRETATION Desired capabilities must meet the listed criteria in Req. P17 to be a valid FCF desired capability or feature.	FCF A-Spec
ENGINEERING RESPONSE COMPLY	BSD

SRED REQUIREMENT Req. P18 - Specific technologies or engineering solution verbiage associated with FCF science requirements do not constitute requirements on the FCF project team to implement that technology or solution.	SRED Sec. 1.3.4.3
ENGINEERING INTERPRETATION Verbiage in the SRED that implies specific technologies or engineering solutions should not be construed as requirements.	FCF A-Spec Sec. 3.2.2.3
ENGINEERING RESPONSE COMPLY This is understood.	BSD

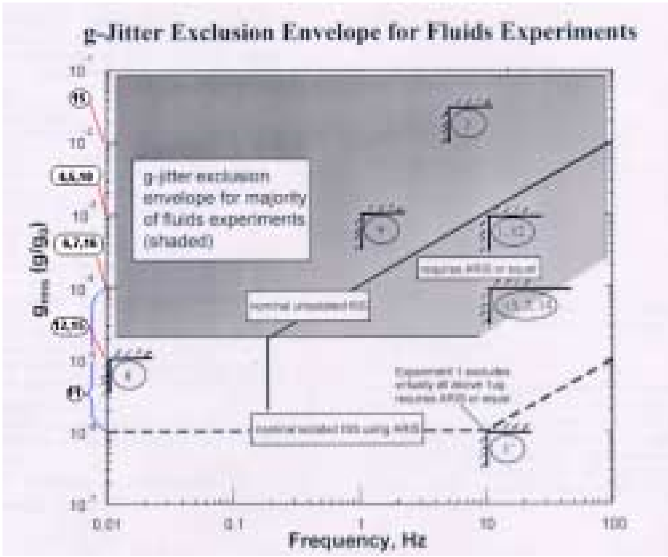
SRED REQUIREMENT Req. P19 - The FCF developer shall endeavor to ascertain the underlying functional requirement implied by a suggested implementation and meet that functional requirement provided that the implied requirement meets Req. P16. The developer shall use similar logic for implied desired capabilities that shall meet Req. P17.	SRED Sec. 1.3.4.3
ENGINEERING INTERPRETATION When documenting compliance with the scientific requirements in the SRED, the FCF developer should state the original requirement, and, if necessary, the developer's interpretation of the implied requirement or desired capability.	FCF A-Spec Sec. 3.2.2.3
ENGINEERING RESPONSE COMPLY An assessment of the Basis Experients for Combustion and Fluids has been performed and the results have been documented in Appendices A and B to this document. Functional requirements derived from this exercise have been manifested therein in the form of required equipment and capabilities to be provided by FCF. These requirements will also be manifested in the rack level specifications for CIR, FIR, and SAR.	BSD

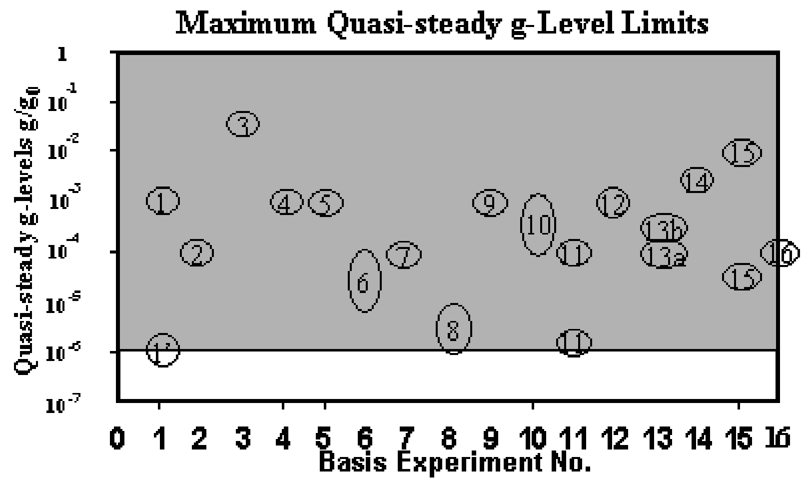
SRED REQUIREMENT Req. P20 – Compliance to science requirements must be shown by the completed facility. Generally, the approach to indicating compliance centers on analysis of FCF's ability, augmented by PI hardware, to perform the Basis Experiments while providing the capabilities implies by the science requirements. Subsequently, the completed hardware shall be tested to verify the hardware performance assumed for the analyses.	SRED Sec. 1.3.4.3
ENGINEERING INTERPRETATION The completed hardware shall be tested to verify the hardware performance assumed for the analyses.	FCF A-Spec
ENGINEERING RESPONSE COMPLY Compliance to science requirements has been provided by showing 3-D layout and modeling of the CIR and FIR set of identified real experiments. This is shown in Appendices A and B of this document. This modeling encompasses the use of the combustion element (CIR and SAR) and fluids element (FIR and SAR). Compliance to the Basis Experiments will be demonstrated at the package level and documented in the individual package science verification reports. Analysis shows that the FCF, augmented with PI-provided equipment, complies with the science requirements.	BSD

SRED REQUIREMENT Req. F1 - FCF shall provide a work volume dedicated to Fluid Physics experimentation. A majority of this volume shall nominally be set aside for PI hardware that may be unique to a specific experiment. The volume set aside shall be adequate to allow set-up and operation of at least 80% of the Fluid Physics Basis Experiments.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. F1 - FCF shall provide a work volume dedicated to Fluid Physics experimentation. A majority of this volume shall nominally be set aside for PI hardware that may be unique to a specific experiment. The volume set aside shall be adequate to allow set-up and operation of at least 80% of the Fluid Physics Basis Experiments.	FIR B-Spec Sec. 3.2.1.4
ENGINEERING RESPONSE COMPLY The Fluids Integrated Rack provides a science volume of approximately 490 liters (89 x 111 x 50 cm) for accommodating fluids physics experiments, or more than 40% of the available rack volume. The science volume mounting area will be 60 cm x 90 cm x 70 to 100 cm depending on the configuration of the hardware with respect to the connectors and UMLs. The actual usable volume available to the PI will be approximately 300 liters when access to optics bench mounted universal mounting locations (UMLs) and connectors for PI electrical power, data, etc. are considered. The science volume normally contains two facility-provided cameras and associated lenses, mirrors, and support electronics, and can accommodate experiment packages up to double middeck locker size (55 x 45 x 28 cm or 70 liters) with full facility providing imaging and illumination capabilities, and as large as 89x 111x 50 cm (490Liters), when facility provided imaging and illumination capabilities are not required. Unused science volume may be available for spare test cells or other PI-specific equipment. This volume is expected to be sufficient to accommodate the full set of basis experiments, with the caveat that some reduction in science is expected for experiment f3, due to an inability to accommodate the requested length of the test cell. Conceptual layouts of all 16 Basis Experiments on the FIR optics bench have been used to show compliance with this requirement and are provided in Appendix B to this document. * The volume available for science will be augmented with the addition of the SAR, by approximately two double middeck lockers. SAR will provide additional stowage for PI test cells and other hardware, as well as a capability to perform limited stand alone fluids experiments.	BSD Sec. B.2.3.3.1, B.2.3.3.2, B.3.1

SRED REQUIREMENT Req. F2 - FCF shall be capable of accommodating fluid physics PI hardware test cells and containers in the range of sizes and capabilities required by the basis experiments.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. F2 - FCF shall be capable of accommodating fluid physics PI hardware test cells and containers in the range of sizes and capabilities required by the basis experiments.	FIR B-Spec Sec. 3.2.1.5
ENGINEERING RESPONSE COMPLY The FIR imaging hardware is designed for nominal fields of view of 10 x 10 X 10 cm. Test cells sizes larger than 10 x 10 x 10 can easily be accommodated, but larger imaging fields of view will require PI-provided optics. Overall PI-specific hardware packages up to double middeck locker size (55 x 45 x 28 cm or 70 liters) will retain full facility-provided imaging capabilities. Test cells and PI-specific hardware packages of up to 89 x 111 x 50 can be accommodated when facility provided imaging and illumination is not required. * The addition of the SAR will permit additional test cells per PI to be accommodated (additional matrix points) by providing additional stowage.	BSD Sec. B.2.3.5.3.1.5

SRED REQUIREMENT Req. F3.1 - FCF shall be capable of providing a microgravity environment (at the test sample) that accommodates the envelope of limiting accelerations identified for the fluid physics basis experiments. Operational protocols may be used to support compliance with this requirement (e.g., scheduling to avoid major disturbances). Figures F3a and F3b are graphical statements of the requirements to be enveloped. Figure F3a illustrates the approximate upper limits on quasi-steady acceleration for each basis experiment. Figure F3b illustrates the excluded zone for g-jitter.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. F3.1 - FCF shall be capable of providing a microgravity environment (at the test sample) that accommodates the envelope of limiting accelerations identified for the fluid physics basis experiments. Operational protocols may be used to support compliance with this requirement (e.g., scheduling to avoid major disturbances). Figures F3a and F3b are graphical statements of the requirements to be enveloped. Figure F3a illustrates the approximate upper limits on quasi-steady acceleration for each basis experiment. Figure F3b illustrates the excluded zone for g-jitter.	FIR B-Spec Sec. 3.2.1.6.1
ENGINEERING RESPONSE COMPLY FIR will provide a microgravity environment which meets the requirements for the fluids basis experiments, assuming that the predictions of ARIS performance and the ISS environment are accurate. Recent issues regarding ARIS performance are assumed to be resolvable prior to FIR launch. The micro-gravity environment at the test cell is a function of the micro-gravity environment input to the rack by ISS, of the attenuation of the environment by the Active Rack Isolation System (ARIS), and of the vibration and attenuation of the rack and rack-mounted equipment. The predicted ISS micro-gravity environment input to the rack is shown in the attached figures with the predicted environment provided to the PI by the ARIS-equipped FIR shown as shaded. The FIR will be designed to provide the best microgravity environment possible for the test cell, through provisions for the ARIS system and good engineering design of the facility structure, mechanisms, and other equipment. Microgravity analysis, supported by testing in the GRC Microgravity Emissions Laboratory, will be performed to validate assumptions regarding FIR equipment-induced vibrations and structural damping.	BSD Sec. 5.2.4 5.1.3.2 5.1.3 5.1.3.1





* The microgravity environment following the addition of SAR may be slightly degraded due to the addition of rack-to-rack cabling. All rack-to-rack cabling will be fiber-optic to minimize transmission of vibration.

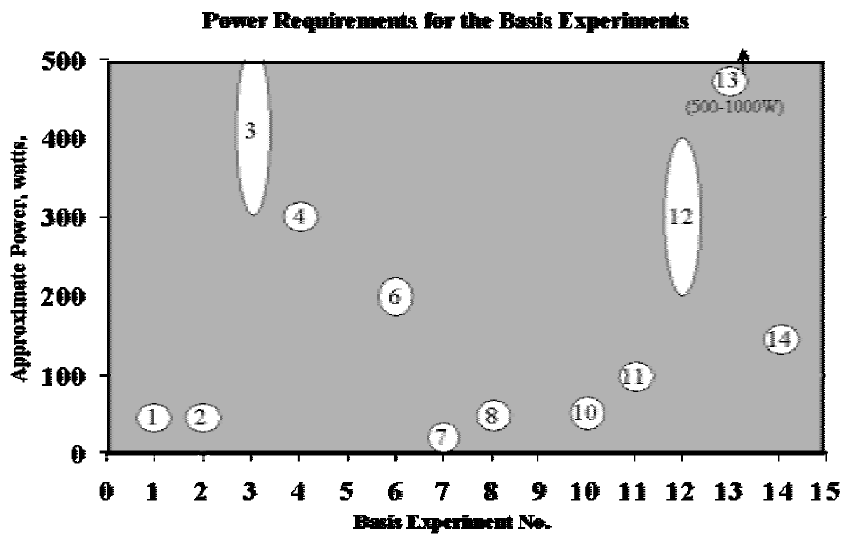
SRED REQUIREMENT Req. F3.2 – FCF shall accommodate an acceleration measurement device as close as practical to the test cell. It shall be capable of measurements in three simultaneous orthogonal directions at levels from 10^{-2} to 10^{-6} g/g_0 and frequencies from 0.01 to 300 Hz. Accuracy shall be within 10 percent of selected full-scale acceleration range. The data shall be available in near real time and post mission. .	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. F3.2 - FCF shall accommodate an acceleration measurement device as close as practical to the test cell. It shall be capable of measurements in three simultaneous orthogonal directions at levels varying (not simultaneous) from 10^{-2} to 10^{-6} g/g_0 and frequencies from 0.01 to 300 Hz, or as necessary to meet the requirements of the basis experiments. Accuracy shall be within 10 percent of selected full-scale acceleration range. The data shall be available in near real time and post mission.	FIR B-Spec Sec. 3.2.1.6.2
ENGINEERING RESPONSE COMPLY FIR will comply with the requirement by incorporating a relocatable SAMS FF accelerometer head, which can be located near the PI hardware package or on the rear of the optics plate. Data will be collected and stored with the other experiment data, or downlinked in near real-time, as necessary. The performance of the system will be equivalent to the SAMS II system, with resolution in the 1 micro-g range and accuracy of 10% or better. Multiple sampling rates of up to 800 Hz will be supported, sufficient to measure frequencies in the 200 Hz range. This is sufficient to meet the requirements for all basis experiments. * Addition of the SAR to FCF does not affect this capability.	BSD Sec. B.2.3.3

SRED REQUIREMENT Req. F4.1 - FCF shall provide stable temperatures within the fluid physics work volume in the range of 20 to 30 C during periods of operation.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. F4.1 - FCF shall provide stable temperatures within the fluid physics work volume in the range of 20 to 30 C during periods of operation.	FIR B-Spec Sec. 3.2.1.7
ENGINEERING RESPONSE COMPLY The FIR will provide an ambient air environment in the science volume for the PI hardware of between 23 and 30 degrees C. An analysis has been performed to evaluate compliance with this requirement. Reference document FIR-ANA-0201. The air input to the FIR science volume will be provided directly from Air Thermal Control Unit (ATCU) heat exchanger. All FIR heat will be rejected to the ISS Moderate Temperature Loop (MTL). ISS allocates cooling water to FIR based on anticipated heat loads (in accordance with the proposed experiment timeline) such that the rack water outlet temperature is maintained at 19.4 degrees C over the inlet temperature (nominally 18 degrees C). Cooling water is normally reduced whenever the rack heat load is reduced. Current estimates indicate that the ambient air in the science volume under these conditions will be in the range of 23 to 30 degrees C, depending on experiment configuration and heat dissipation. The FIR also provides PI hardware with a water cooling resource at 18 C which can be used to reduce or stabilize ambient temperatures for the PI provided hardware. The water is provided via the ISS Moderate Temperature Loop (MTL) and is delivered to the PI hardware via the secondary water loop of the Water Thermal Control System (WTCS). This approach would be most effective when applied to those experiments using the Experiment Package concept, which would be the majority of the basis experiments, and to those experiments requiring heat rejection in excess of approximately 500 watts Repeatability between experiment runs of better than plus or minus 1 C, as provided by the facility, is predicted. Additional precision can be accomplished through the use of PI-provided temperature control hardware, for which FIR can provide power, control, and heat rejection. On-orbit verification of the PI volume and the temperature is provided by the AMA. * The ambient thermal environment in the FIR science volume will not be affected by the addition of the SAR.	BSD Sec. 5.2.1 5.2.2 B.2.3.10 B.3.1

SRED REQUIREMENT Req. F4.2 - The facility shall support the ability of PI hardware to maintain required test cell (and other) temperatures inside the PI hardware over a minimum range of -20 to 100 C.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. F4.2 - The facility shall support the ability of PI hardware to maintain required test cell (and other) temperatures inside the PI hardware over a minimum range of -20 to 100 C by providing data acquisition, power, control, and heat rejection, etc. for selected PI heaters and coolers.	FIR B-Spec Sec. 3.2.1.8
ENGINEERING RESPONSE COMPLY The FIR will provide interfaces to PI-provided hardware for controlling power, cooling, and thermometry to enhance the capability to precisely control PI hardware temperatures. This will be accomplished in accordance with standard facility provisions for providing power and data acquisition and control, as addressed in requirements F7.1, 7.2, 21.1, 21.2, 22.1, 22.2, 25, 26, 29, and 32. Control of PI hardware temperatures outside the normal ambient range is expected to require containment inside a PI-provided experiment container. * The capability of FCF to meet this requirement is not affected by the addition of the SAR.	BSD Sec. B.2.3.7

SRED REQUIREMENT Req. F5 – FCF shall provide the capability to control air circulation within and around measurement systems that are susceptible to disturbance caused by uncontrolled air circulation. At times the air must be still and at times it must be circulated to obtain relatively uniform conditions.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. F5 - FCF shall provide the capability to control air circulation within and around measurement systems that are susceptible to disturbance caused by uncontrolled air circulation. At times the air must be still and at times it must be circulated to obtain relatively uniform conditions.	FIR B-Spec Sec. 3.2.1.9
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE The FIR will meet the intent of the requirement for providing forced air flow by providing a standard nominal air flow through the science volume. This air flow is required by ISS to be present whenever the rack is powered in order to perform fire detection. The requirement to provide a convection-free environment for sensitive measurement systems will be met through use of a PI provided Experiment Package (EP), which can be used to contain experiment hardware and components. This approach will permit the performance of critical imaging tasks such as interferometery by locating sensitive optical paths inside the EP (i.e., splitting and recombining the beam internal to the EP). * FCF capability to meet air circulation requirements will not change as a result of the addition of the SAR.	BSD Sec. 5.2.1

SRED REQUIREMENT Req. F6 – FCF shall provide physical and procedural controls to limit levels of contamination on the optical elements of optical systems during handling, setup, operation, and storage. Optical element transmission shall remain greater than 60 percent of the day 1 value (previously verified). Replacement of contaminated elements can be used as one aspect of control.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. F6 - FCF shall provide physical and procedural controls to limit levels of contamination on the optical elements of optical systems during handling, setup, operation, and storage. Optical element transmission shall remain greater than 60 percent of the day 1 value (previously verified). Replacement of contaminated elements can be used as one aspect of control.	FIR B-Spec Sec. 3.2.1.10
ENGINEERING RESPONSE COMPLY The FIR will employ a number of design and procedural controls to manage contamination. Protection against intrusion of dust and other contaminants from the ISS environment is provided via a rack design, which is sealed to the extent possible. The FIR Air Thermal Control System (ATCS) contains a dust and particle filter. Particle sizes greater than 300 microns are filtered. The FIR is designed to minimize exchange of air with the US Lab, but is not hermetically sealed. Rack air flow is such that any particulates that do find their way into the rack through the bottom of the rack at the interface with ISS will first pass through the rack air filter before reaching optical components. Contamination entering the science volume during experiment installation or reconfiguration when the rack door is open will be cleared by operating the rack fan/air filter following door closure. Particulate matter, which does collect on optical surfaces, will be cleaned via the use of compressed gas or distilled water. Contamination of optical elements with films or other materials may require either replacement of the affected component or cleaning in the ISS Glovebox Facility. Test images, taken at periodic intervals, and perhaps utilizing a test target, will be used to assess the level of optical system contamination. The FIR will be designed to facilitate removal, inspection, and cleaning of internally mounted equipment should the test imagery reveal degradation in image quality. Design of both FIR and PI-specific equipment will minimize the generation of volatiles and particulates, through proper selection of materials and lubricants, and by providing containment when generation of volatiles or particulates cannot be avoided. * FCF capability to limit levels of contamination in the science volume is not affected by the addition of the SAR.	BSD Sec. B.2.3.3.1

SRED REQUIREMENT Req. F7.1 -FCF shall provide PI-provided hardware with adequate power per the estimates shown in figure F7. At a minimum, this power shall be 500 W for a period of weeks (when needed) and 1000 W for periods of at least 15 minutes (when needed). Figure F7 is a graphical statement of the requirements.	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. F7.1 - FCF shall provide PI-provided hardware with adequate power per the estimates shown in figure F7. At a minimum, this power shall be 500 W for a period of weeks (when needed) and 1000 W for periods of at least 15 minutes (when needed). Figure F7 is a graphical statement of the requirements.	FIR B-Spec Sec. 3.2.2.3.2
ENGINEERING RESPONSE COMPLY PI hardware will nominally have available up to 6 channels of 28 VDC power at 4 amps per channel from the EPCU for a total of 672 Watts. For experiments requiring additional power, 3 channels of 120 VDC power at 4 Amps per channel will be supplied for a total of 1440 W. It should be noted that the rack cooling configuration is only designed to remove 500 W of PI produced heat via air cooling. Sustained additional power usage by the PI, without corresponding decreases in facility power consumption or reliance on water cooling, will result in an overall rack temperature increase. As shown in the attached figure, the FIR can provide sufficient electrical power to meet the needs of all basis experiments.  * FCF capability to meet experiment power requirements is not affected by the addition of the SAR.	BSD Sec. B.2.3.4, 5.1.2

SRED REQUIREMENT Req. F7.2 - FCF shall provide 5 (or more) individually controlled sources of electric power for use by PI hardware (minimum capability would be five 28 volt, 4 amp circuits).	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. F7.2 - FCF shall provide 5 (or more) individually controlled 28 volt, 4 (or more) ampere power circuits for use by PI hardware. Analysis shall be used to verify compliance with this requirement.	FIR B-Spec Sec. 3.2.2.3.2
ENGINEERING RESPONSE COMPLY PI hardware will nominally have available 6 channels of 28 VDC power at 4 amps per channel from the EPCU for a total of 672 Watts. For experiments requiring additional power, 3 channels of 120 VDC power at 4 Amps per channel will be supplied for a total of 1440 W. It should be noted that the rack cooling configuration is only designed to remove 500 W of PI produced heat via air cooling while maintaining the science volume ambient temperature in the 20 to 30 degrees C range. Sustained additional power usage by the PI, without corresponding decreases in facility power consumption or reliance on water cooling, will result in an overall rack temperature increase. As shown in the above figure, the FIR can provide sufficient electrical power to meet the needs of all identified basis experiments. * FCF capability to meet experiment power requirements is not affected by the addition of the SAR.	BSD Sec. B.2.3.4

SRED REQUIREMENT Req. F7.3 - FCF shall provide PI hardware with easy access to cooling adequate to dissipate the power provided to the PI hardware. Access to both liquid cooling and air cooling is required.	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. F7.3 - FCF shall provide PI hardware with easy access to cooling adequate to dissipate the power provided to the PI hardware. Access to both liquid cooling and air cooling is required.	FIR B-Spec Sec. 3.2.2.3.3
ENGINEERING RESPONSE COMPLY FIR provides a nominal air cooling capability for PI hardware of up to 500 watts while maintaining the science volume ambient temperature in the range of 23 to 30 degrees C. Sustained PI heat loads higher than 500 watts without use of water cooling will result in ambient temperatures higher than 30 degrees C in the science volume. This result has been document in FIR-ANA-0201, “FIR Thermal Analysis and Specifications for PDR” * FCF capability to provide cooling during experiment operations is not affected by the addition of SAR.	BSD Sec. B.2.3.2 B.2.3.3.1 B.2.3.3.2

SRED REQUIREMENT Req. F8 - FCF shall provide uniform, broad band lighting (nominally white light) at the test cell. Intensity and uniformity shall be consistent with image resolution requirements. The absolute mean intensity shall variable over a wide range. The mean intensity shall be determinable with an accuracy of approximately 1 percent before, during, and after an experiment test point run. The mean intensity shall be stable within approximately 1 percent during a test point run. The dimensions of the illuminated area shall be capable of adjustment over a range of sizes as required by the basis experiments; however, the nominal size shall be an approximately 10cm x 10cm illuminated field of view.	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. F8 - FCF shall provide uniform, broad-band lighting (nominally white light) at the test cell, with intensity, uniformity, and stability sufficient to meet image resolution requirements.. The absolute mean intensity shall be variable over a wide range. The mean intensity shall be determinable with an accuracy of approximately 1 percent before, during, and after an experiment test point run. The mean intensity shall be stable to within approximately 1 percent during a test point run. The dimensions of the illuminated area shall be capable of adjustment over a range of sizes as required by the basis experiments; however, the nominal size shall be an approximately 10cm x 10cm illuminated field of view.	FIR B-Spec Sec. 3.2.1.11
ENGINEERING RESPONSE PARTLY COMPLY The FIR will provide backlighting (consisting of 2 lamps) that is delivered via fiber bundles. One fiber bundle will terminate into a fiber weave panel, which will support the 10 cm × 10 cm field of view as required. The second bundle will interface to a focusing lens. If a diverging lens is used, the illuminated area can be greater than 10 cm × 10 cm but the uniformity will be compromised. The lamps will provide illumination in the visible wave-length (from ≈ 380 – 740 ηm.) This white light package can deliver light to the test cell at up to 0.05 mW/cm2 with a uniformity of 10%, a stability of 1%, and a mean intensity known to within 2%. FIR/FCF will not meet the requirements for adjustable size. * FCF illumination capabilities are not affected by the addition of the SAR.	BSD Sec. B.2.3.5.4.1

SRED REQUIREMENT Req. F9.1 - FCF shall provide laser sources, optical systems, power, and control to enable laser illumination over the range of wavelength, polarization, power, and other characteristics required by the majority of fluid physics basis experiments. The facility shall provide collimated beams and light sheets having adjustable size and position. Laser light sources used for background lighting shall be subject to the same intensity uniformity standards as the broadband background lighting sources (req. F8).	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. F9.1 - FCF shall provide laser sources, optical systems, power, and control to enable laser illumination over the range of wavelength, polarization, power, and other characteristics required by the majority of fluid physics basis experiments. The facility shall provide collimated beams and light sheets having adjustable size and position. Laser light sources used for background lighting shall be subject to the same intensity uniformity standards as the broadband background lighting sources (req. F8).	FIR B-Spec Sec. 3.2.1.12
ENGINEERING RESPONSE PARTLY COMPLY The FIR provides three facility lasers as the standard on-orbit complement. The lasers provided in the FIR include: 1. One Nd:YAG laser whose (CW) output is at least 50 mW at the test cell (high power, good beam quality) 2. Two high-powered diode lasers (10 mW at 680 nm). These lasers together meet all requirements for wavelength, polarization, power, intensity, stability, and other characteristics as necessary to meet requirements for the basis experiments. The facility provides collimated beams of 25 mm and 50 mm. All facility lasers are fiber coupled and can be provided to the PI through fiber interfaces suitable for custom manipulation by PI provided optics. The facility does not provide light-sheet optics due to the need for custom designed optics for each PI and the requirement for proximity to the test cell, normally located inside the Experiment Package or other PI provided container. A comparison of the facility-provided hardware vs. PI-provided hardware necessary to meet this requirement has been	BSD Sec. B.2.3.5.4

made in Appendix B to this document. * FCF capabilities with regard to laser light illumination are not affected by the addition of the SAR.	

SRED REQUIREMENT Req. F10 - FCF shall provide PI hardware access to the ISS vacuum vent system.	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. F10 - FCF shall provide PI hardware access to the ISS vacuum vent system.	FIR B-Spec Sec. 3.2.1.13
ENGINEERING RESPONSE COMPLY FIR will provide access to ISS vacuum resource service (VRS) and vacuum exhaust service (VES) for experiments meeting ISS requirements for acceptable materials to be vented. These accommodations will be provided as a standardized interface to the PI-specific hardware package via quick disconnect. Verification of the composition of the materials/gasses to be vented may be required prior to accessing the vent/vac port, and access may not be possible for hazardous, incompatible, or reactive fluids, as specified by ISS. Due to anticipated infrequent use of the VRS (sustained hard vacuum), VES, and GN_2, the PI will be required to provide valves and valve controls. Access to these resources will be provided via a Gas Interface System panel that is located in the science volume on the side of the rack. * SAR will provide access to vent/vac/GN2 resources for payloads in the SAR, in the same manner as is done for FIR.	BSD Sec. 3.6

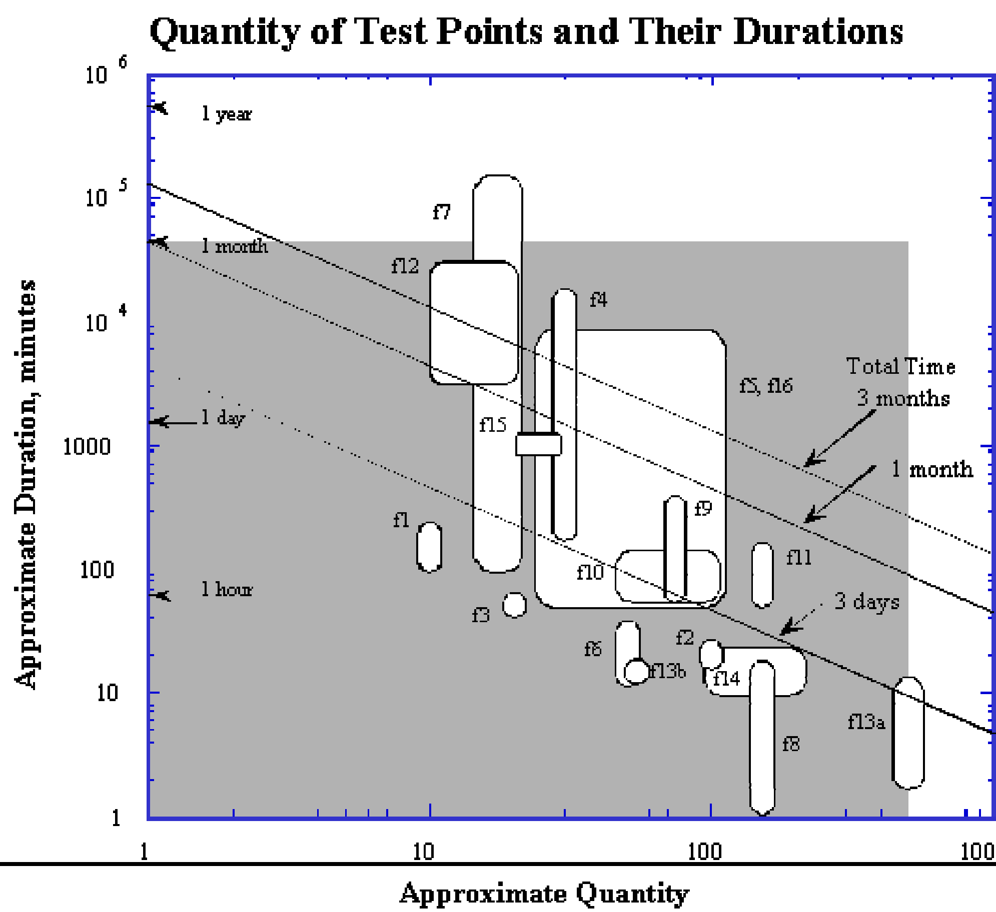
SRED REQUIREMENT Req. F11 - FCF shall provide on-orbit stowage having power and cooling to accommodate such needs as thermal control, stirring, and tumbling experiment samples whenever required.	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. F11 - FCF shall provide on-orbit stowage having power and cooling to accommodate such needs as thermal control, stirring, and tumbling experiment samples whenever required.	FIR B-Spec Sec. 3.2.1.14
ENGINEERING RESPONSE COMPLY FIR can provide limited stowage in the science volume for spare PI test cells and other equipment up to the maximum volume available in the science area and subject to PI mass allocations up to the total mass limit of the FIR. However, stowed items may potentially interfere with imaging and illumination tasks. Total PI equipment in excess of 490 liters (based on PI experiment volume fitting into a 90.8 cm width x 119.0 cm length x 50.8 cm height envelope) will require stowage in another ISS location. ISS provided stowage is a negotiated resource with ISS. * SAR will provide additional stowage of roughly the equivalent of the FIR science volume. Standard power (28 VDC) will be provided. However, stirring, cooling below ambient, etc. must be accomplished using PI provided hardware.	BSD Sec. B.2.3.3.1, B.2.3.3.3

SRED REQUIREMENT Req. F12 – FCF shall accommodate the quantity of test points and test point durations of the fluid physics basis experiments per the estimates in figure F12.	SRED Sec. 2.2.3
ENGINEERING INTERPRETATION Req. F12 – FCF shall accommodate the quantity of test points and test point durations of the fluid physics basis experiments per the estimates in figure F12. Figure F12 is a graphical statement of the requirements to be enveloped.	FIR B-Spec Sec. 3.2.1.15
ENGINEERING RESPONSE COMPLY FIR has been designed to accommodate the quantity of test points and test point durations of the fluids physics basis experiments as indicated in the requirement F12 figure. FIR has no limited life items, consumables, or required maintenance intervals less than the maximum experiment duration identified in the figure. Also, the Mean Time Between Failure (MTBF) for the rack as a whole will be greater than the maximum experiment test point durations identified. A typical FIR operational scenario has been developed and is provided in the FCF BSD (FCF-DOC-003C), and in more detail in Appendix C to this document. Although each Basis Experiment is unique, a set of opeerational guidelines has been developed using Basis Experiment averages for resource usage. While the FIR Ops Concept is envisioned to be based primarily on a nominal 8-hour workday, FIR can support continuous operation, if necessary, for periods of up to several weeks, with only the constraints of ISS resource allocations and video data storage as limitations. FIR has been designed to minimize use of ISS resources and, to the extent possible, not be the constraining factor in experiment operations. Other possible limitations imposed on experiment durations by ISS, in addition to communications downlink, include micro-gravity periods, which are not guaranteed over 30-days, as well as crew time, usage of GN2 and vent/vac resources, electrical power, and total energy. Current FIR data storage capability is less than the expected daily storage requirement for some basis experiments. However,	BSD Sec. B.2.3.6.5, B.3.2.3, C.3.2.2.2

the current daily downlink limit from ISS is estimated to be 20 gigabytes per day and FIR will provide storage capacity on removable hard drives for the PI data of at least 73 gigabytes. Thus FIR can provide long-term storage of video data for return to earth, in effect relaxing the ISS imposed downlink constraint. The basis experiment data storage requirements are expected to be reduced when further definition is made to the concepts, and also as video compression schemes are implemented. FIR data storage capacity may increase as storage technology improves.

Further definition of the Basis Experiment concepts on which the nominal operations concept was developed is provided in Appendix B to this document.

* FCF capabilities to meet requirements for quantity of test points and test point durations are expected to be enhanced with the addition of SAR, due to additional flexibility in scheduling experiment operations and a resultant easing of the video data storage and downlink limitations.



SRED REQUIREMENT Req. F13.1 - FCF shall provide a set of imaging systems (e.g., subassemblies incorporating cameras, lenses, mirrors, et al) covering, nominally, the entire light spectrum. They shall be the types and quantities required by the basis experiments.	SRED Sec. 2.3.1
ENGINEERING INTERPRETATION Req. F13.1 - Req. F13.1 - FCF shall provide a set of imaging systems (e.g., subassemblies incorporating cameras, lenses, mirrors, et al) covering, nominally, the entire light spectrum. They shall be the types and quantities required by the basis experiments.	FIR B-Spec Sec. 3.2.1.16
ENGINEERING RESPONSE COMPLY FIR provides three standard facility cameras. The current concept includes two high-resolution monochrome cameras with macroscopic and high-resolution lenses as well as a 3-chip color CCD camera. A facility ultra-high frame-rate camera (1000 frames per second) is slated to become a standard facility capability. In order to avoid use of limited-life storage media, the FIR Imaging Systems will be primarily digital. An exception is the color camera, which will be analog, with the analog signal converted to digital in the IPSU. Both types of facility-provided cameras utilize silicon detectors and normally cover the wavelength range from 400 to 700 nm, but can be configured to provide imagery in the near infrared (to 1050 nm) and near ultraviolet. FIR provides the capability to image from at least two cameras simultaneously and provides motor control for camera translation, focusing, and image tracking. Nominally, one video channel will be downlinked in near real time, however, the capability exists with multiplexing or data compression techniques to downlink two image channels. All cameras are capable of being relocated to various locations on the optics plate to maximize experiment layout flexibility. All image data will be tagged with appropriate time information. Appendix B to this document provides additional information regarding how the FIR cameras meet the needs of the majority of the fluids physics basis experiments. * FCF capabilities to meet imaging requirements are enhanced with the addition of the SAR due to the inclusion of the ultra-high frame-rate camera, and additional image processing/storage capabilities.	BSD Sec. B.2.3.5.1, B.2.3.5.3.1.3, B.2.3.5.3, B.2.3.5.3.1.5, B.2.3.5.3.1.6, B.2.3.3.3

SRED REQUIREMENT Req. F13.2 - FCF shall accommodate PI provided cameras and supporting hardware, which are compatible with power, data acquisition, and work volume capabilities.	SRED Sec. 2.3.1
ENGINEERING INTERPRETATION Req. F13.2 - FCF shall accommodate PI-provided cameras and supporting hardware, which are compatible with power, data acquisition, and work volume capabilities.	FIR B-Spec Sec. 3.2.1.16.1
ENGINEERING RESPONSE COMPLY The facility-provided color camera utilizes a standard RS-170A electrical interface. This standardized interface is available for use by PI-provided analog cameras. Since facility-provided digital camera electrical and connector interfaces are not standardized, PI-provided digital cameras must be able to utilize the existing IPSU image processing cards and internal cabling. PI-provided cameras, when substituted for facility cameras, may utilize the existing facility motor controllers. * FCF capabilities to accommodate PI-provided cameras are enhanced with the launch of SAR due to an additional camera electrical interface available for PI use.	BSD Sec. B.2.3.5.1

SRED REQUIREMENT Req. F14.1 - FCF shall accommodate simultaneous imaging of the test cell from at least two orthogonal directions as required by the basis experiments.	SRED Sec. 4.3.2
ENGINEERING INTERPRETATION Req. F14.1 - FCF shall accommodate simultaneous imaging of the test cell from at least two orthogonal directions as required by the basis experiments.	FIR B-Spec Sec. 3.2.1.17
ENGINEERING RESPONSE COMPLY FIR nominally provides two orthogonal views of the test cell using two digital high-resolution cameras. Additional views may be possible, using either the facility provided color camera or a PI-provided camera, depending on the experiment design. The flexibility of the facility optics plate design allows for simultaneous imaging of different areas of the test cell, different fields of view/magnification, and different imaging techniques, including interferometry, to be used for each camera. FIR is limited to a maximum of 3 cameras operating simultaneously, but does not preclude the use of more than 3 cameras total. * FCF capability to perform simultaneous imaging from at least two directions is enhanced with the addition of SAR due to the inclusion of the ultra-high frame rate camera capability with SAR.	BSD Sec. B.2.3.5.3.1, B.2.3.6.2

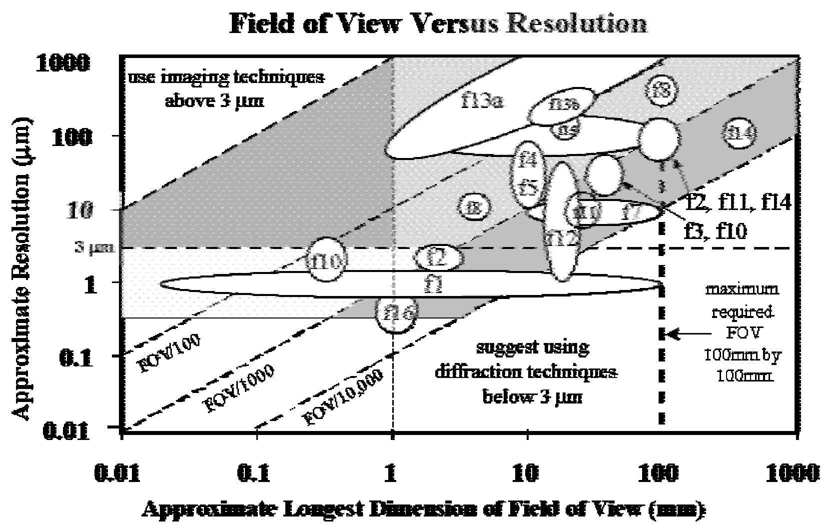
SRED REQUIREMENT Req. F14.2 - FCF shall provide down link for at least two imaging channels in near real time with frame-rate and resolution adequate to monitor the progress of the test point, for image analysis, and for interactive control of the basis experiments.	SRED Sec. 4.3.2
ENGINEERING INTERPRETATION Req. F14.2 - FCF shall provide down link for at least two imaging channels in near real time with frame-rate and resolution adequate to monitor the progress of the test point, for image analysis, and for interactive control of the basis experiments.	FIR B-Spec Sec. 3.2.1.18
ENGINEERING RESPONSE COMPLY FIR provides the capability to image from at least two cameras simultaneously. Nominally, one video channel will be downlinked in near real time; however, the capability exists with multiplexing or data compression techniques to download two image channels in this manner. Resolution and frame-rate will be sufficient to monitor the progress of the experiments, to perform cursory image analysis, and for interactive control of the experiments, if necessary, within ISS constraints. Additional downlinks of digital image data may be available in near real-time via the HRDL. Downlink bandwidth is ISS limited and downlink coverage is expected to be available approximately 40 to 60% of each orbit. * FCF capability to downlink two imaging channels simultaneously is not changed with the addition of the SAR.	BSD Sec. 5.2.4.2, B.2.3.6.1

SRED REQUIREMENT Req. F15.1 - FCF shall provide positioners, optical systems, power control, and procedures to reproducibly position and align light sources, optics, and other experimental components located within the dedicated fluid physics volume. The relative positions of components shall be reproducible and knowable with the accuracy and precision required by the majority of basis experiments.	SRED Sec. 4.3.2
ENGINEERING INTERPRETATION Req. F15.1 - FCF shall provide the capability and procedures to reproducibly position and align light sources, optics, and other experimental components located within the dedicated fluid physics volume. The relative positions of components shall be reproducible and knowable with the accuracy and precision required by the majority of basis experiments.	FIR B-Spec Sec. 3.2.1.19
ENGINEERING RESPONSE COMPLY FCF provides an optics bench for mounting PI hardware with two hardware attachment schemes. The design utilizes an integral T-groove mounting rail, with detents located at 25 mm centers. The bench also includes standard M6 mounting holes located on 100 mm centers. Both attachment schemes provide equipment positioning within the 2 mm and 2 degrees tolerances that are sufficient to meet the needs of the basis experiments. Deformation due to thermal expansion/contraction will be within allowable tolerances and will be taken into account, as necessary, as part of experiment operations. For those instances where additional precision or accuracy are required, FIR can accommodate techniques such as direct referencing of position-critical equipment and test cells to the same mechanical interface and the use of micro-positioning motors. * FCF capability to reproducibly position equipment in the science volume is not affected by the addition of the SAR.	BSD Sec. B.2.3.3.2, B.2.3.5.3.1.6

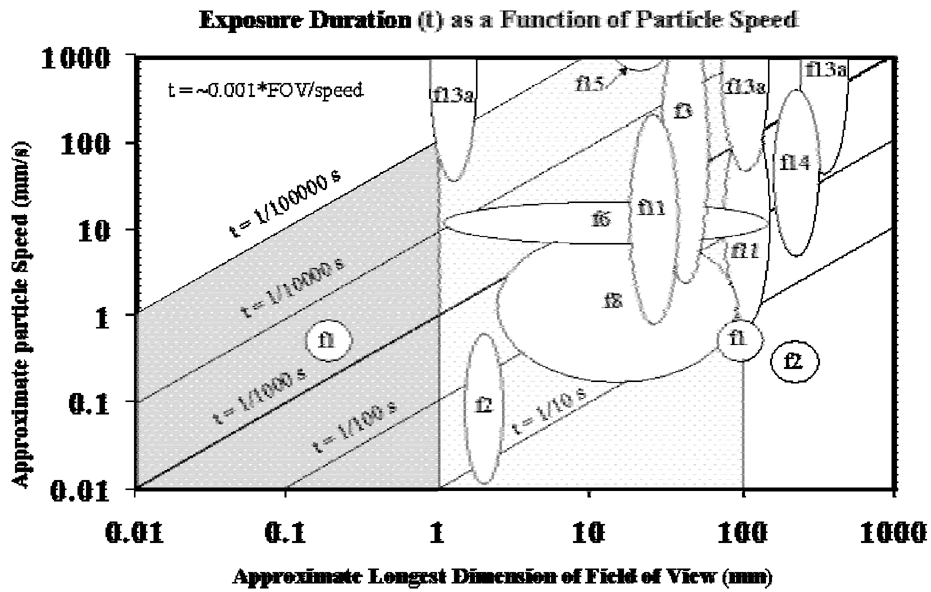
SRED REQUIREMENT Req. F15.2 - Position and alignment adjustment of PI-provided optical components with a precision of approximately a micron or less relative to other optical components shall be supported by the FCF system, as required for practical implementation of the basis experiments.	SRED Sec. 4.3.2
ENGINEERING INTERPRETATION Req. F15.2 - Position and alignment adjustment of PI-provided optical components with a precision of approximately a micron or less relative to other optical components shall be supported by the FCF system, as required for practical implementation of the basis experiments.	FIR B-Spec Sec. 3.2.1.20
ENGINEERING RESPONSE COMPLY FIR will support precision alignment of components via techniques such as direct referencing of position-critical equipment and test cells to the same mechanical interface and the use of micro-positioning motors with resolutions on the order of microns. Range of travel using these devices will be small, however, and may best be accomplished via use of PI hardware. It may be desireable for position-critical components to be located inside the Experiment Package. * FCF capability to precisely position optical components in the science volume is not affected by the addition of the SAR.	BSD Sec. B.2.3.5.3.1.6

SRED REQUIREMENT Req. F16 - FCF imaging shall accommodate the ranges of field of view and resolution necessary to support the basis experiments per the estimates in figure F16. Figure F16 is a graphical statement of the requirements to be enveloped.	SRED Sec. 2.3.3
ENGINEERING INTERPRETATION Req. F16 - FCF imaging shall accommodate the ranges of field of view and resolutions necessary to support the basis experiments per the estimates in figure F16. Figure F16 is a graphical statement of the requirements to be enveloped.	FIR B-Spec Sec. 3.2.1.2.1, 3.2.1.2.2
ENGINEERING RESPONSE COMPLY FIR utilizes state-of-the-art cameras, lenses, and optical components to provide an imaging system, which meets the requirements of the basis experiments. FIR imaging systems will provide fields of view between 1 and 100 mm. Fields of view smaller than 1 mm, not requiring a proportionate increase in magnification, may be obtained using the same hardware by cropping the image after it is acquired. The FIR will provide high-resolution (monochrome) cameras with pixel counts of 1024 x 1024. This will provide a sensor resolution of 1/1024 of the FOV, or 1 micrometer and 100 micrometers, respectively, for images whose FOVs are 1 mm and 100 mm. The resolution of the color imagery will be approximately 1/500 of the FOV. The facility will provide lenses whose performance worse than the diffraction limit is consistent with the high-resolution CCDs cell size. The high-magnification lens has a resolution of 3 micrometers. This or any other facility-provided lens may be replaced with a PI-provided lens. Digital images may be post-processed by the PI to obtain sub-pixel resolutions. The FIR will support obtaining resolutions below the limit of optical imaging by accommodating interferometric techniques, with the addition of PI hardware.	BSD Sec. B.2.3.5.3.1.5, B.2.3.5.3.1.1 B.2.3.5.3.1.5

* FCF capability to meet FOV vs. Resolution requirements is not affected by the addition of the SAR.



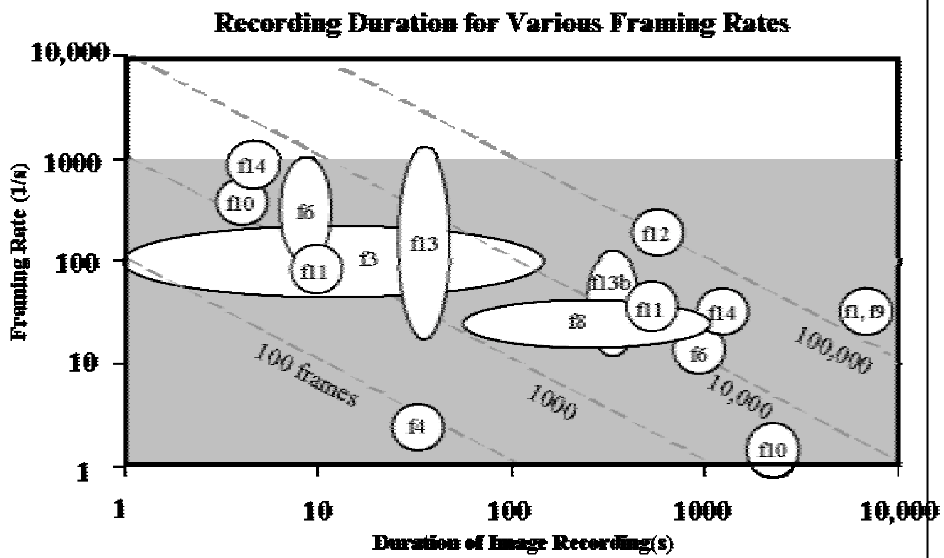
SRED REQUIREMENT Req. F17 - FCF shall accommodate the range of fields of view (FOV) and expected particle velocities required by the basis experiments per the estimates in figure F17. Figure F17 is a graphical statement of the requirements to be enveloped.	SRED Sec. 2.3.3
ENGINEERING INTERPRETATION Req. F17 - FCF shall accommodate the range of fields of view (FOV) and expected particle velocities required by the basis experiments per the estimates in figure F17. Figure F17 is a graphical statement of the requirements to be enveloped.	FIR B-Spec Sec. 3.2.1.23
ENGINEERING RESPONSE COMPLY The FIR imaging system design has been optimized to meet the requirements for as many of the basis experiments as possible. The current FIR concept utilizes two high-resolution and one color camera as the baseline facility capability. An ultra-high frame-rate camera is planned for inclusion as a facility capability with the launch of SAR. With the basic capability as planned, the facility meets the exposure requirements for exposures as short as one-half millisecond and for fields of view between 1 and 100 mm, as shown in the attached chart. FOVs greater than 100 mm are not provided as standard views, but can be accommodated with PI-provided lenses. FOVs less than 1 mm are accomplished by cropping the image (see f16). The 1024 x 1024 sensor in the high-resolution cameras contains an electronic shutter whose exposure can be remotely selected from 5 values between 1/60th second and 1/1000th second. In addition, integration for an exposure of up to 1.0 second is possible. Exposure times of less than 1/1000 of a second will require PI-provided strobe lighting, the HFR camera, or a combination of both. An ultra-high frame-rate camera, to be included as a standard FIR capability with the launch of SAR is expected to provide exposure times as short as 1/10,000th second, extending the basic facility capability to cover the majority of the basis experiments.	BSD Sec. B.2.3.5.3, B.2.3.5.3.1.1 B.2.3.5.3.1.2 B.2.3.5.3.1.3

* FCF's ability to meet particle speed vs. FOV requirements is enhanced with the addition of the SAR due to the inclusion of the FIR ultra-high frame-rate camera as a standard facility capability.	

SRED REQUIREMENT	SRED Sec.
Req. F18 - FCF shall provide the range of framing rate and range of quantities of images required by the basis experiments per figure F18. Figure F18 is a graphical statement of the requirements to be enveloped.	2.3.3
ENGINEERING INTERPRETATION Req. F18 - FCF shall provide the range of framing rate and range of quantities of images required by the basis experiments per figure F18. Figure F18 is a graphical statement of the requirements to be enveloped.	FIR B-Spec Sec. 3.2.1.24
ENGINEERING RESPONSE COMPLY The FIR will meet all requirements for frame-rate vs. duration when the SAR is launched to allow the addition of a facility ultra-high frame-rate camera. Prior to the launch of SAR, the highest frame-rate provided by the facility is 110 frames per second. Following the launch of SAR, the highest frame-rate provided by the facility is expected to be 1000 FPS at 512 x 512 pixels or greater if lower resolution is adequate. The FIR will provide two digital high-resolution cameras capable of acquiring images at up to 110 fps. Following the launch of SAR, the FIR capabilities will also include an ultra-high frame-rate camera, which is expected to provide 512 x 512 image output at 1000 fps. Illumination may be an issue at rates above 500 FPS. Data acquisition/storage rates on the facility hardware currently limit some of the cameras' capabilities, both in image acquisition and recording duration. For durations between 1 and 6 seconds, the facility will provide up to 1000 frames per second, limited by the video acquisition memory size. For non-continuous durations over 2000 seconds, the size of the hard drive is the limitation.	BSD Sec. B.2.3.5.3 B.2.3.5.3.1.3, B.2.3.5.3.1.1

Recording Speed vs. Image Size

		Horizontal Resolution		
		512	256	128
	512	1000	1800	3000
Vertical	256	2000	3600	5700
Resolution	128	3900	6700	11,200
	64	7800	13,000	19,800
	32	14,300	22,700	32,000



* FCF capabilities are increased with the addition of the SAR due to the inclusion of the ultra-high frame-rate camera as a standard facility capability.

SRED REQUIREMENT Req. F19.1 – FCF shall provide at least one removable media recording device capable of recording the equivalent of 2 hours of standard video data.	SRED Sec. 2.3.3
ENGINEERING INTERPRETATION Req. F19.1 – FCF shall provide at least one removable media recording device capable of recording the equivalent of 2 hours of standard video data.	FIR B-Spec Sec. 3.2.1.25
ENGINEERING RESPONSE PARTLY COMPLY The FCF and FIR plan to utilize the ISS video recorders to meet the requirement to provide 2 hours of video data storage. The FIR/FCF will not meet the requirement to provide removable media for recording up to 2 hours of standard video data. FIR can store up to approximately 1 hour of digitized NSTC video data in the IOP. * FCF capability to provide removable media storage will not be affected by the addition of the SAR.	BSD Sec. 5.2.4

SRED REQUIREMENT Req. F20.1 - FCF shall provide diagnostics commonly needed by Fluid Physics experiments.	SRED Sec. 2.3.3
ENGINEERING INTERPRETATION Req. F20.1 - FCF shall provide diagnostics commonly needed by the basis experiments.	FIR B-Spec Sec. 3.2.1.26
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR will meet the requirement to provide commonly used diagnostics commonly needed by the basis experiments. An assessment of which diagnostic techniques should be provided/accommodated by FIR and to what extent is provided below.	BSD Sec. B.2.3.5.1 B.3.1.2 B.2.3.5.4.1

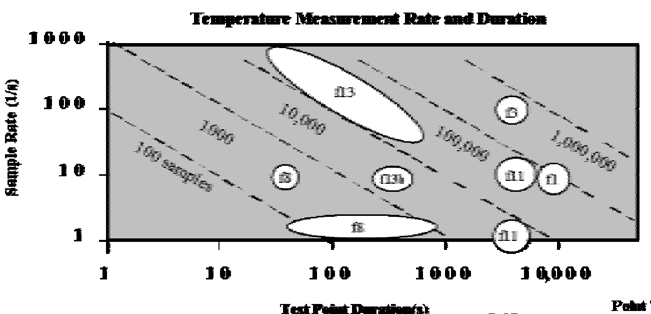
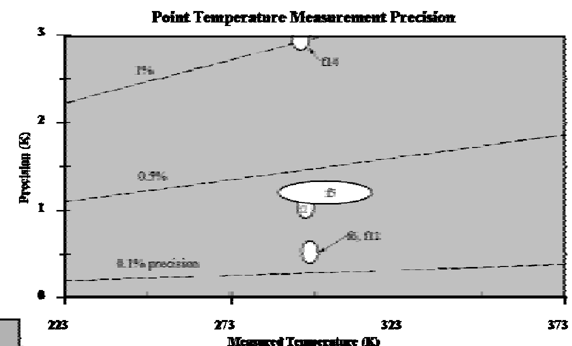
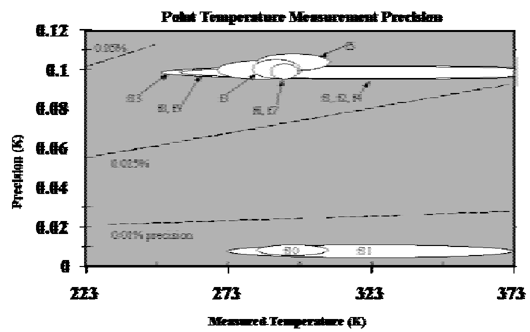
DIAGNOSTIC TECHNIQUE	BASIS EXPERIMENT	RECOMMENDED BASELINE CAPABILITY	**RECOMMENDED UPDATED CAPABILITY**	**FIR Provided Capability**	**Comments**
General imaging	f1 to f16	multiple views, zoom capability, particle tracking, color and b&w, frame rates to 300 per sec	high frame rates (to 2000 per sec)	Y	FIR Cameras can be used as general imaging cameras with FIR provided lenses or PI provided lenses
IR imaging	f1, f11		as required	N	FIR will not preclude the use of a PI provided IR Camera and lens
Video microscopy	f1, f2, f10, f15,f16	2 views		Y	If magnifications greater than optem lens can provide are required, PI must supply appropriate lens
Static and dynamic light scattering	f4, f5, f7, f12, f16	required			

Shadowgraph	f11	required		Y	FIR provides a light source capable of producing shadowgraphs but PI must provide pin hole and imaging screen		
Schlieren			as required	N	The light sources and imagers that are provided by FIR could be used in a Schlieren system but FIR does not provide the optics for this type of imaging system. At this time there is no Basis Experiment requiring this imaging technique.		
Color schlieren			as required	N	The light sources and imagers that are provided by FIR could be used in a Color Schlieren system but FIR does not provide the focusing optics for this type of imaging system. At this time there is no Basis Experiment requiring this imaging technique.		
Particle image velocimetry	f1, f2, f3, f10, f11	required		N*	The light sources and imagers that are provided by FIR could be used for PIV but FIR does not provide the light sheet optics for this technique. Additionally it is felt that the light sheet optics for each of the experiments listed is to specific that it would require a unique light sheet generator for every experiment.		

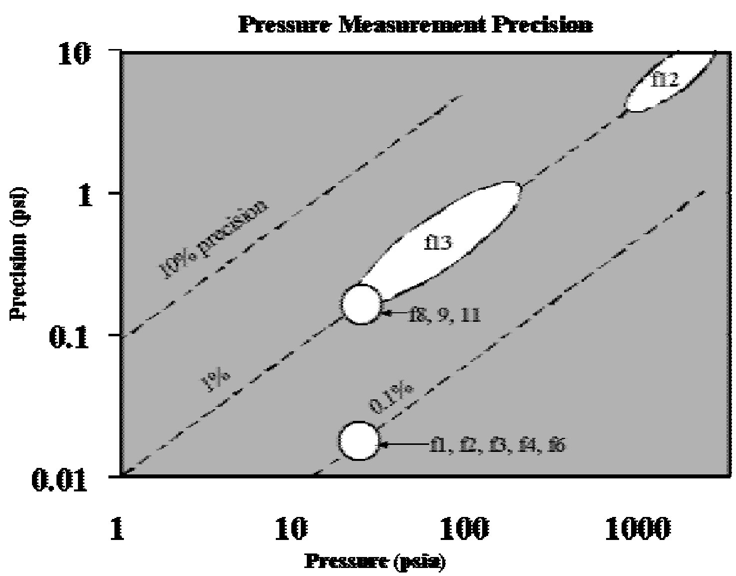
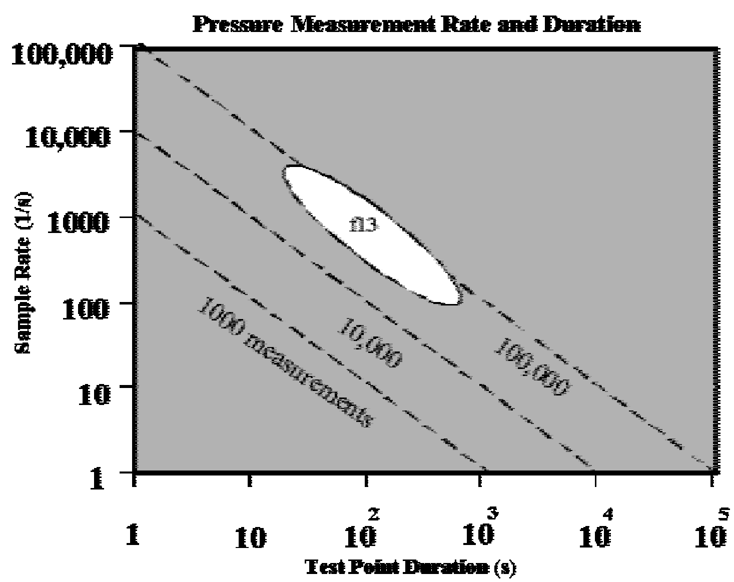
Laser induced fluorescence	f10		as required	Y	This is a technique that can be performed using the FIR provided lasers, provided the PI provided the sample containing particles that could absorb and radiate the energy from the FIR lasers.		
Mach-Zehnder interferometry	f8, f9, f12		as required	N* **	FIR does not provide the two beam splitters required for this interferometric technique. However FIR does provide an illumination source and mirrors that could be configured into this type of interferometer.		
Michelson interferometry	f1, f12		as required	N* **	FIR does not provide the beam splitter and compensating plate required for this interferometric technique. However FIR does provide an illumination source and imager that could be configured into this type of interferometric configuration.		
Twyman-Green interferometry	f12		as required	N* **	FIR does not provide the beam splitter required for this interferometric technique. However FIR does provide an illumination source, collimator, mirror, and imager that could be configured into this type of interferometric configuration.		
Point diffraction interferometry	f8, f9		as required	N* **	This interferometric technique is similar to the Twyman-Green interferometer above.		

Shearing interferometry	f1, f8 f9, f12, f14	required		N* **	FIR does not provide the shear plate required for this interferometric technique. However FIR does provide an illumination source and imager that could be configured into this type of interferometric configuration.
Liquid crystal point diffraction interferometry	f8, f9		as required	N* **	
Laser feedback interferometry	f1		as required	N* **	The lasers provided by FIR are not configured to accommodate this type of interferometric technique.
Surface profilometry	f11	required		N*	FIR can supply a laser for use in a interferometer configuration to measure surface shapes or roughness.
Ronchi (surface slopes measurement)	f11		as required	N	FIR does not supply a Ronchi grating
Laser Induced Photochemical Anemometry			as required	N	Not required by any basis experiments
Confocal and fluorescence microscopy	f16		as required	N**	Experiment specific
Laser tweezers	f16		as required	N	Experiment specific
Spectrophotometry	f16		as required	N	Experiment specific
Spectroscopy; DTS DWS	f15		as required	N	Experiment specific

* This hardware requires integration into the PI test cell for optimum efficiency. ** Setup and configuration of these items would require real time positional alignment with real time feedback to the investigator. * FCF capability to meet these diagnostics requirements will be enhanced with the addition of the SAR, due to the inclusion of the ultra-high frame-rate camera, additional stowage, and image processing and storage capability.	

SRED REQUIREMENT Req. F21.1 - FCF shall be capable of accommodating acquisition and storage of temperature data from a variety of transducers at various ranges, precisions, and data rates per the estimates in figures F21a, F21b, and F21c. Figures F21a, F21b, and F21c are a graphical statement of the requirements to be enveloped.	SRED Sec. 2.3.4
ENGINEERING INTERPRETATION FCF shall be capable of accommodating acquisition and storage of temperature data from a variety of transducers at various ranges, precisions, and data rates per the estimates in figures F21a, F21b, and F21c. Figures F21a, F21b, and F21c are a graphical statement of the requirements to be enveloped	FIR B-Spec Sec. 3.2.1.27
ENGINEERING RESPONSE COMPLY FIR meets all requirements for measurements of temperature over the stated ranges, sample rates, precisions, and experiment durations. PI-specific conditioning may be required.  * FCF capability to meet data acquisition and storage of temperature data is not affected by the addition of SAR.	BSD Sec. B.2.3.7.1 B.2.3.8.3

SRED REQUIREMENT Req. F21.2 - FCF shall identify temperature measurement instruments or techniques appropriate to the needs of the basis experiments (as implied by figures F21a, F21b, and F21c) and verify their performance in FCF systems. The transducer specifications, test information and, samples shall be made available to PI hardware developers.	SRED Sec. 2.3.4
ENGINEERING INTERPRETATION FCF shall identify temperature measurement instruments or techniques appropriate to the needs of the basis experiments (as implied by figures F21a, F21b, and F21c) and verify their performance in FCF systems. The transducer specifications, test information and, samples shall be made available to PI hardware developers.	FIR B-Spec Sec. 3.2.1.28
ENGINEERING RESPONSE DO NOT COMPLY FIR will provide the interface specifications necessary to permit selection of temperature transducers compatible with the facility. Because of changing technology and specific PI requirements, this is felt to provide a more flexible means for PIs to meet their science requirements. * FCF capability to meet this requirement is not affected by the addition of the SAR.	BSD Sec. N/A

SRED REQUIREMENT Req. F22.1 - FCF shall be capable of accommodating acquisition and storage of pressure data at various ranges, precisions, and data rates per the estimates in figures F22a and F22b. Figures F22a and F22b are a graphical statement of the requirements to be enveloped.	SRED Sec. 2.3.4
ENGINEERING INTERPRETATION FCF shall be capable of accommodating acquisition and storage of pressure data at various ranges, precisions, and data rates per the estimates in figures F22a and F22b. Figures F22a and F22b are a graphical statement of the requirements to be enveloped.	FIR B-Spec Sec. 3.2.1.29
ENGINEERING RESPONSE COMPLY FIR meets all requirements for measurements of pressure over the stated ranges, sample rates, precisions, and experiment durations. PI-specific conditioning may be required.   * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. B.2.3.7.1 B.2.3.8.3

SRED REQUIREMENT Req. F22.2 - FCF shall identify pressure measurement instruments or techniques appropriate to the needs of the basis experiments (as implied by figures F22a and F22b) and verify their performance in FCF systems. The transducer specifications, test information, and samples shall be made available to PI hardware developers.	SRED Sec. 2.3.4
ENGINEERING INTERPRETATION FCF shall identify pressure measurement instruments or techniques appropriate to the needs of the basis experiments (as implied by figures F22a and F22b) and verify their performance in FCF systems. The transducer specifications, test information, and samples shall be made available to PI hardware developers.	FIR B-Spec Sec. 3.2.1.30
ENGINEERING RESPONSE DO NOT COMPLY FIR will provide the interface specifications necessary to permit selection of pressure transducers compatible with the facility. Because of changing technology and specific PI requirements, this is felt to provide a more flexible means for PIs to meet their science requirements. Sensors may not be available that provide useful information at 100,000 Hz sampling rate, which may exceed the response time of the instruments. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. N/A

<table>
<tr><td>SRED REQUIREMENT

Req. F23.1 - FCF shall be capable of accommodating acquisition and storage of force at various ranges, precisions, and data rates per the estimates in figures F23a and F23b. Figures F23a and F23b are a graphical statement of the requirements to be enveloped.</td><td>SRED Sec.

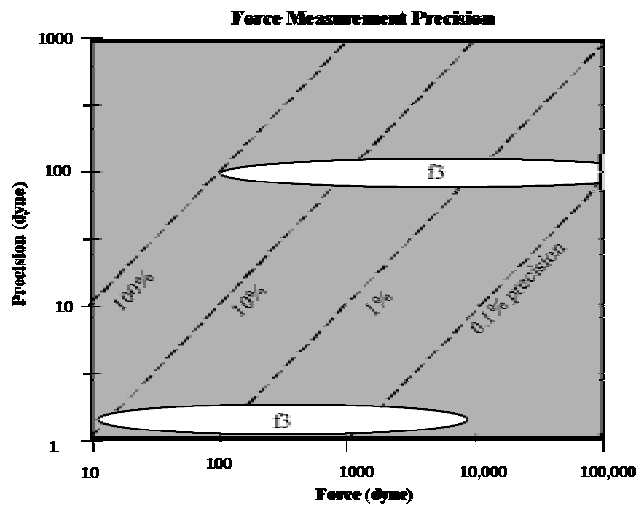
2.3.4</td></tr>
<tr><td>ENGINEERING INTERPRETATION

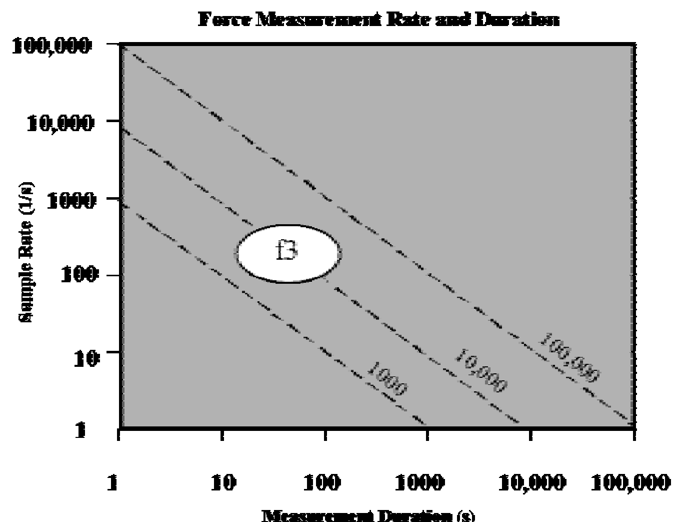
FCF shall be capable of accommodating acquisition and storage of force at various ranges, precisions, and data rates per the estimates in figures F23a and F23b. Figures F23a and F23b are a graphical statement of the requirements to be enveloped.</td><td>FIR B-Spec Sec.

3.2.1.31</td></tr>
<tr><td>ENGINEERING RESPONSE

COMPLY

FIR meets all requirements for measurements of force over the stated ranges, sample rates, precisions, and experiment durations. PI-specific conditioning may be required.





* FCF capability to meet this requirement is not affected by the addition of SAR.</td><td>BSD Sec.

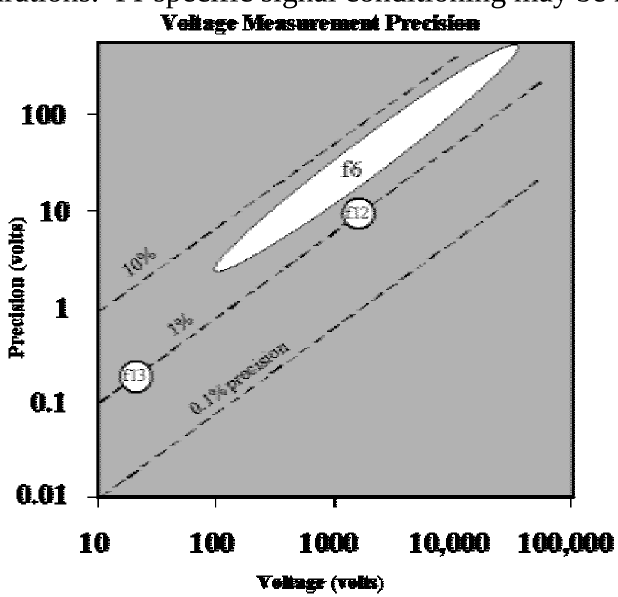
B.2.3.7.1

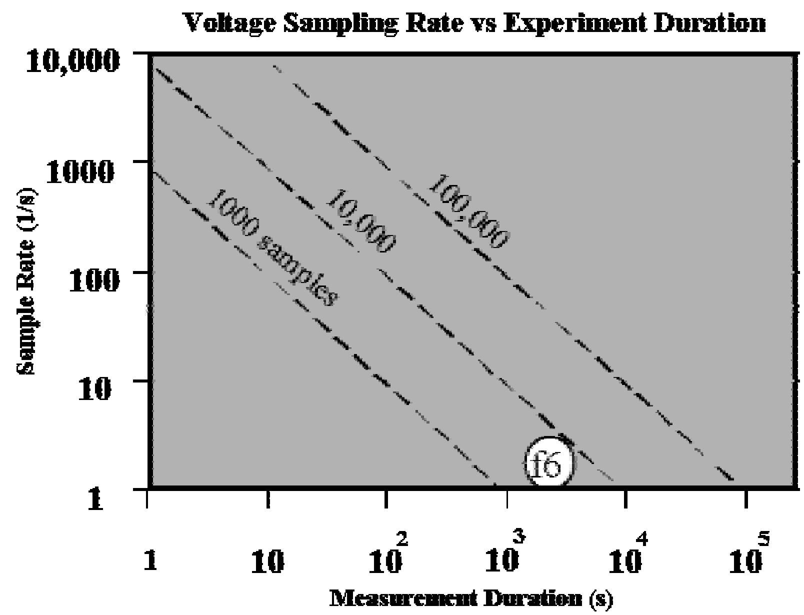
B.2.3.8.3</td></tr>
</table>

SRED REQUIREMENT Req. F23.2 - FCF shall identify force measurement instruments or techniques appropriate to the needs of the basis experiments (as implied by figures F23a and F23b) and verify their performance in FCF systems. The transducer specifications, test information, and samples shall be made available to PI hardware developers.	SRED Sec. 2.3.4
ENGINEERING INTERPRETATION FIR shall identify force transducers appropriate to the needs of the basis experiments (as implied by figures F23a and F23b) and verify their performance in FCF systems. The transducer specifications, test information, and samples shall be made available to PI hardware developers.	FIR B-Spec Sec. 3.2.1.32
ENGINEERING RESPONSE DO NOT COMPLY FIR will provide the interface specifications necessary to permit selection of voltage transducers compatible with the facility. Because of changing technology and specific PI requirements, this is felt to provide a more flexible means for PIs to meet their science requirements. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. N/A

<table>
<tr><td>SRED REQUIREMENT

Req. F24.1 - FCF shall be capable of accommodating acquisition and storage of voltage data at various ranges, precisions, and data rates per the estimates in figures F24a and F24b. Figures F24a and F24b are a graphical statement of the requirements to be enveloped.</td><td>SRED Sec.
2.3.4</td></tr>
<tr><td>ENGINEERING INTERPRETATION

FCF shall be capable of accommodating acquisition and storage of voltage data from a variety of transducers at various ranges, precisions, and data rates per the estimates in figures F24a and F24b. Figures F24a and F24b are a graphical statement of the requirements to be enveloped.</td><td>FIR B-Spec Sec.
3.2.1.33</td></tr>
<tr><td>ENGINEERING RESPONSE
COMPLY
FIR meets all requirements for voltage measurement over the stated ranges, sample rates, precisions, and experiment durations. PI-specific signal conditioning may be required.




* FCF capability to meet this requirement is not affected by the addition of SAR.</td><td>BSD Sec.
B.2.3.7.1
B.2.3.8.3</td></tr>
</table>

SRED REQUIREMENT Req. F24.2 - FCF shall identify voltage measurement instruments or techniques appropriate to the needs of the basis experiments (as implied by figures F24a and F24b) and verify their performance in FCF systems. The transducer specifications, test information, and samples shall be made available to PI hardware developers.	SRED Sec. 2.3.4
ENGINEERING INTERPRETATION FCF shall identify voltage transducers appropriate to the needs of the basis experiments (as implied by figures F24a and F24b) and verify their performance in FCF systems. The transducer specifications, test information, and samples shall be made available to PI hardware developers.	FIR B-Spec Sec. 3.2.1.34
ENGINEERING RESPONSE DO NOT COMPLY FIR will provide the interface specifications necessary to permit selection of voltage transducers compatible with the facility. Because of changing technology and specific PI requirements, this is felt to provide a more flexible means for PIs to meet their science requirements. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. N/A

SRED REQUIREMENT Req. F25 - FCF shall be capable of simultaneously sampling multiple channels of analog signals originating in PI hardware with sampling rates, as required to accommodate the basis experiments.	SRED Sec. 2.4.1
ENGINEERING INTERPRETATION FIR shall be capable of simultaneously sampling multiple channels of analog signals originating in PI hardware with sampling rates, as required to accommodate the basis experiments.	FIR B-Spec Sec. 3.2.1.35
ENGINEERING RESPONSE COMPLY FIR will provide a minimum of 32 differential analog input lines for analog-to-digital conversion of PI data. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. B.2.3.7.1

SRED REQUIREMENT Req. F26 - FCF shall be capable of simultaneously sampling multiple channels of digital signals originating in PI hardware, as required to accommodate the basis experiments.	SRED Sec. 2.4.1
ENGINEERING INTERPRETATION FCF shall be capable of simultaneously sampling multiple channels of digital signals originating in PI hardware, as required to accommodate the basis experiments.	FIR B-Spec Sec. 3.2.1.36
ENGINEERING RESPONSE COMPLY The FIR will provide 24 channels of digital input from the FSAP. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. B.2.3.7.1

SRED REQUIREMENT Req. F27.1 - FCF shall provide non-volatile storage for experiment-specific non-image data (e.g.., transducer readings) as required by the basis experiments but not less than 9 Gbytes shall be provided for the purpose.	SRED Sec. 2.4.2
ENGINEERING INTERPRETATION FCF shall provide non-volatile storage for experiment-specific non-image data (e.g.., transducer readings) as required by the basis experiments. Compliance shall be shown by analysis of the design and as-built configuration combined with performance tests	FIR B-Spec Sec. 3.2.1.46, 3.2.1.40.4
ENGINEERING RESPONSE COMPLY FIR will provide two 18 Gbyte hard drives each in the FSAP and two removable 73 Gbyte hard drives in the IOP. At least 50% of the IOP hard drive space will be available for PI use and approximately 65 Gbytes of each drive in the IOP for PI use. Data is normally stored in the FSAP temporarily, then transferred to the IOP where it can be downlinked or hard drives can be swapped if necessary. Data will remain stored on orbit until confirmation of successful downlink has been received. * FCF capability to meet this requirement will be enhanced by the addition of SAR due to its additional data storage capabilities.	BSD Sec. 5.2.4 B.2.3.6.5 B.2.3.7.1

SRED REQUIREMENT Req. F28.1 - FCF shall provide the capability to time tag all data, including video data relative to an ISS provided timing signal. The time tag shall be of equivalent accuracy and precision to the ISS on-board timing signal or as required by the basis experiments, whichever is less stringent.	SRED Sec. 2.4.2
ENGINEERING INTERPRETATION FIR shall provide the capability to time tag all data, including video data relative to an ISS provided timing signal. The time tag shall be of equivalent accuracy and precision to the ISS on-board timing signal or as required by the basis experiments, whichever is less stringent.	FIR B-Spec Sec. 3.2.1.37
ENGINEERING RESPONSE COMPLY A capability will be provided to have the avioinics clocks in the FSAP resynchronized to the ISS clock via the IOP clock periodically to ensure system accuracy in time tagging of experiment data. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. B.2.3.6.3

SRED REQUIREMENT Req. F28.2 - FCF shall provide the capability to time tag all data relative to an ISS provided clock signal and an FCF provided internal clock signal. The accuracy and precision of the time tag shall be approximately 0.1s and 0.01s, respectively.	SRED Sec. 2.4.2
ENGINEERING INTERPRETATION FCF shall provide the capability to time tag all data relative to an FCF provided internal clock signal. The accuracy and precision of the time tag shall be approximately 0.1s and 0.01s, respectively.	FIR B-Spec Sec. 3.2.1.38
ENGINEERING RESPONSE COMPLY Each digital and video data frame will be tagged with unique identifiers in order to permit reconstruction on the ground should the data streams become disordered. The FIR will time-stamp acquired digital and video data using the FSAP clock with an accuracy of ± 1 millisecond. All data frames, digital or video, collected at 1000 Hz or less, will be individually time tagged. Data taken at rates higher than 1000 Hz will be tagged at 10 millisecond intervals. For those data frames which are not tagged, the time collection will be determined by interpolation. Due to the very low overhead associated with adding time tags to experiment data streams, data tagging will occur at the highest frequency permitted by the system. * FCF capabilities with respect to this requirement are not changed with the addition of the SAR.	BSD Sec.

SRED REQUIREMENT Req. F29 - FCF shall provide multiple channels of analog output. These shall be capable of waveform generation as well as producing point voltage values. The quantity of channels, their accuracy, and their precision shall be adequate to control the basis experiments. At least 16 channels of at least 12-bit analog output shall be provided to experiments that require them.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION FIR shall provide multiple channels of analog output. These shall be capable of waveform generation as well as producing point voltage values. The quantity of channels, their accuracy, and their precision shall be adequate to control the basis experiments. At least 16 channels of at least 12-bit analog output shall be provided to experiments that require them.	FIR B-Spec Sec. 3.2.1.39
ENGINEERING RESPONSE DO NOT COMPLY The facility is capable of supporting 8 channels of analog control at 16-bit resolution via the FSAP based on an evaluation of PI needs. Additional channels may be provided in the FSAP by utilizing the two empty slots in the bus. This would be considered PI provided hardware. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. B.2.3.7.1

SRED REQUIREMENT Req. F30 - The facility shall provide internal and external triggering capability to enable the individual experiments to trigger and correlate various events.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION The facility shall provide internal and external triggering capability to enable the individual experiments to trigger and correlate various events.	FIR B-Spec Sec. 3.2.1.40
ENGINEERING RESPONSE COMPLY FIR will provide internal and external triggering capability. FIR software will be capable of determining whether pre-defined events have occurred using facility or PI provided sensor data and of taking appropriate action. The triggering software may be experiment-specific and will reside in the FSAP. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. B.2.3.8 B.2.3.8.3

SRED REQUIREMENT Req. F31 - FCF shall be capable of simultaneously outputting multiple channels of digital signals to PI hardware, as required to accommodate the basis experiments. At least 16 channels outputting 1-bit at 5 volts shall be provided to experiments that require them.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION FCF shall be capable of simultaneously outputting multiple channels of digital signals to PI hardware, as required to accommodate the basis experiments. At least 16 channels outputting 1-bit at 5 volts shall be provided to experiments that require them.	FIR B-Spec Sec. 3.2.1.41
ENGINEERING RESPONSE COMPLY The FSAP will provide 24 channels of Digital out. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec.

SRED REQUIREMENT Req. F32 - FCF shall be able to accommodate experiment specific computer cards (minimum of two card slots) in an FCF computer near the Fluid Physics work volume and to accommodate PI software for experiment control and analysis (i.e., accommodate PI hardware and software).	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION FCF shall be able to accommodate experiment-specific computer cards (minimum of two card slots) in an FCF computer near the Fluid Physics dedicated volume and to accommodate PI software for experiment control and analysis (i.e., accommodate PI hardware and software).	FIR B-Spec Sec. 3.2.1.42
ENGINEERING RESPONSE COMPLY FIR computer systems has allocated a minimum of 2 slots of a 4 slot 3u CPCI bus system in the FSAP. These slots may be configured as necessary by the PI. PI software will be accommodated in the FSAP. * FCF capability to meet this requirement is not affected by the addition of SAR.	BSD Sec. B.2.3.2.7

SRED REQUIREMENT Req. F33 - The FCF shall provide a high performance computing and data-handling capability for onboard image and data processing to enable telescience adaptation of science procedures which actually depend on more data than is feasible to down/up link with the ISS limited bandwidth.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION FCF computer capabilities shall provide more functions than just data collection and transmittal. FCF computers shall, to the extent possible, provide a means to minimize uplink/downlink data requirements, and if possible, to facilitate telescience.	FIR B-Spec Sec. 3.2.1.43
ENGINEERING RESPONSE COMPLY In addition to data acquisition and control, FIR avionics systems are capable of performing data compression, event detection, etc. With the addition of SAR, FCF capabilities are increased through the addition of a dedicated video post-processor/downlink processor. A discussion of how video data might be handled for the FIR is provided in Appendix C to this document. * FCF capability to meet this requirement is enhanced by the addition of SAR.	BSD Sec. B.2.3.5.3.1.2 B.3.2.1

SRED REQUIREMENT Req. C1 - The FCF shall provide a combustion chamber with adequate volume and dimensions to accommodate the test sections of basis experiments c1 through c11. Requirements are shown in Figures C1a-b.	SRED Sec. 3.2.1
ENGINEERING INTERPRETATION The combustion chamber will have an adequate free volume and dimensions to accommodate test sections and PI-specific hardware of basis experiments c1 through c11. For experiments c3, c4, c9, c10 and c11, the test section height will be accommodated within the combustion chamber diameter.	CIR B-Spec Sec. 3.2.1.4, 3.2.1.5
ENGINEERING RESPONSE COMPLY The combustion chamber provides a maximum free volume of 100 liters. The length to diameter ratio is 2.25 (using a maximum length of 900 mm and a diameter of 400 mm).	BSD Sec. A.2.2.4.1

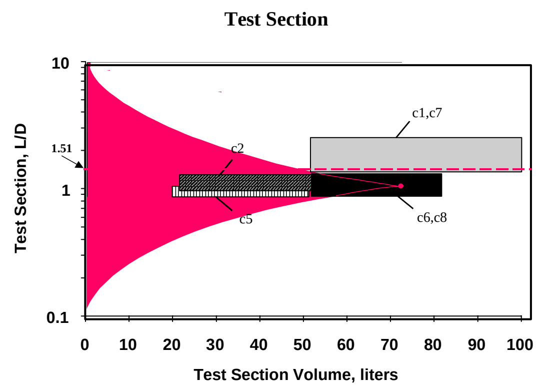


Figure C1a

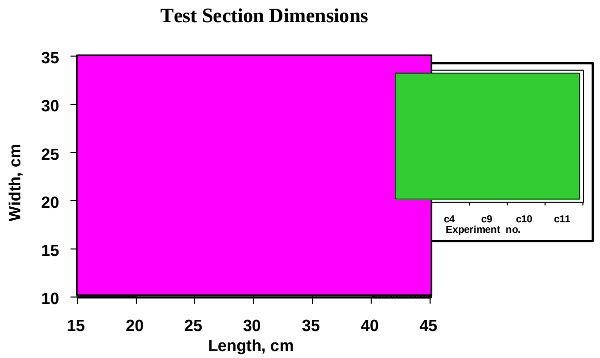


Figure C1b

SRED REQUIREMENT	SRED Sec.
Req. C2 - The FCF shall provide a capability for storage, distribution and mixing of fuels and oxidizer. Fuels can be gaseous (e.g., hydrocarbons, alkenes and selected aromatics); liquid (e.g., alcohols and alkanes); or solid fuels (e.g., polymers, wood, cloth, and selected metals). The FCF shall also provide power and controls for igniting fuel/ oxidizer mixtures using experiment provided igniter mechanisms. Typical ignition mechanisms include hot wires and surfaces, sparks, and lasers.	3.2.1
ENGINEERING INTERPRETATION	CIR B-Spec Sec.
FCF shall provide a capability for storage, distribution and mixing of fuels and oxidizer. It shall also provide power and controls for igniting fuel/oxidizer mixtures using experiment provided igniter mechanisms. Fuels can be gaseous (e.g., hydrocarbons, alkenes and selected aromatics); liquid (e.g., alcohols and alkanes); or solid fuels (e.g., polymers, wood, cloth, and selected metals). Typical ignition mechanisms include hot wires and surfaces, sparks, and lasers.	3.2.1.7, 3.2.1.8, 3.2.1.9
ENGINEERING RESPONSE	BSD Sec.
COMPLY WITH PI HARDWARE Storage, distribution, and mixing of fuels and oxidizer are provided by the FOMA. Power for ignition is provided through the combustion chamber instrumentation ring. Controls for igniting are PI-specific Hardware. Electrical and mechanical interface specifications are provided between the Optics Bench and the PI-specific Electronics Package, and for the interface resource ring feedthrus.	A.2.2.4.2, A.2.2.4.1, A.2.3.4

SRED REQUIREMENT Req. C3 - The FCF shall provide an environment which minimizes the "quasi-steady state" accelerations, vibratory disturbances, and transient impulses. Requirements are shown in Figure C3.	SRED Sec. 3.2.1
ENGINEERING INTERPRETATION FCF shall provide an environment that minimizes "quasi-steady state" accelerations, vibratory disturbances, and transient impulses.	CIR B-Spec Sec. 3.2.1.11
ENGINEERING RESPONSE COMPLY The Active Rack Isolation System (ARIS) will be installed in the CIR. ARIS will keep the rack internal environment well below this requirement when subjected to the projected ISS environment. The FCF racks will be optimized to minimize internally generated disturbances by careful design practice, purchase of low vibration fans and other rotating devices, development of balance procedures for rotating devices and isolation of vibrating components when necessary.	BSD Sec. A.5.1.3

SRED REQUIREMENT Req. C4 - The FCF shall provide pressure containment and control for initial gas pressures in the range of 0.02 to 3 atmosphere. The FCF shall provide containment and control for the pressure to remain constant within 5% throughout the test time. It shall provide containment for pressure increases to 9 atmosphere (absolute). The FCF shall provide control for initial gas temperatures of 268 to 320 K. Condensed phase fuel temperatures shall be controllable to ±1 K in the range 268 to 315 K at the start of testing.	SRED Sec. 3.2.2
ENGINEERING INTERPRETATION FCF shall provide pressure containment and control for initial gas pressures in the range of 0.02 to 3 atmosphere. FCF shall provide containment and control for the pressure to remain constant within 5% throughout the test time. It shall provide containment for pressure increases to 9 atmosphere (absolute). The FCF shall provide control for initial gas temperatures of 268 to 320 K. Condensed phase fuel temperatures shall be controllable to ±1 K in the range 268 to 315 K at the start of testing. The requirements are shown in Figures C5a-b.	CIR B-Spec Sec. 3.2.1.12, 3.2.1.13, 3.2.1.14
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FCF provides pressure containment and control for initial gas pressures up to 8 atmospheres. Pressures beyond 8 atmospheres require a PI provided containment vessel within the combustion chamber. (This supplementary vessel must be limited in volume such that a rupture would not increase the outer chamber pressure to more than 8 atmospheres.) FCF does not provide control of gas temperatures beyond the effect of the ambient conditions of the ISS US Lab Module. The ISS US Lab Module temperature will be controlled from 290° to 301° K per SSP 57000 Rev. B Table 3.9.3.4-1 Environmental Conditions on ISS. Any further control is provided by PI-specific hardware. Electrical and mechanical interface specifications are provided between the Optics Bench and the PI-specific Electronics Package and for the interface resource ring feedthrus.	BSD Sec. A.2.3.4.2, A.2.2.4.1, A.2.3.4

Operating Conditions in Pressure and Temperature

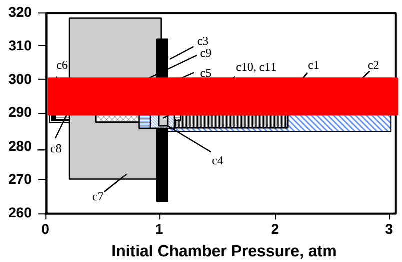


Figure C4a

Operating Conditions in Fuel and Oxidizer Temperature

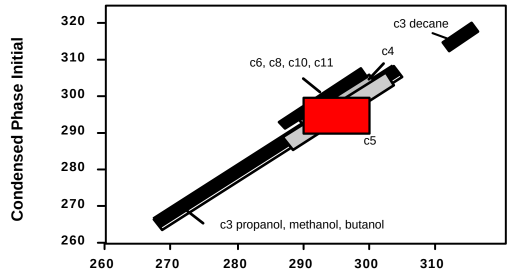


Figure C4b

SRED REQUIREMENT	SRED Sec.
Req. C5 - The FCF shall provide oxidizer, which will generally be a mixture of oxygen and one or more diluents. Oxygen concentration in this mixture will vary over the range of 0 to 70%. Selected requirements are shown in Figures C5a-b. The FCF shall also have the capability to dispense pre-mixed oxidizer/fuel mixtures from gas bottles into the combustion chamber.	3.2.2
ENGINEERING INTERPRETATION	CIR B-Spec Sec.
FCF shall provide oxidizer, which will generally be a mixture of oxygen and one or more diluents. Oxygen concentration in this mixture will vary over the range of 0 to 70%. FCF shall also have the capability to dispense pre-mixed oxidizer/fuel mixtures from gas bottles into the combustion chamber.	3.2.1.16, 3.2.1.17, 3.2.1.18
ENGINEERING RESPONSE	BSD Sec.
COMPLY FCF will deliver an oxygen/diluent environment by combinations of any of three standard oxidant bottles: 1 L 85% Oxygen, 2.25 L 50% Oxygen or 3.8 L 30% Oxygen (all with balance diluent). ISS Nitrogen can be used to dilute to the proper mixture. FCF can dispense pre-mixed PI-provided oxidizer/fuel mixtures from gas bottles into the combustion chamber. Pure fuels will be delivered from the Fuel/Premixed Fuel Supply Manifold and mixed with the oxidizer and diluent from combinations of the remaining three manifolds in either 1, 2.25 or 3.8 liter bottles. ISS limits the exhaust to not exceed 30% O_2; however, FCF is designed to accommodate mixtures of up to 85% O_2 inside the test chamber. After completion of an experiment run, the test chamber is filled with nitrogen, then the contents are sampled, using the Gas Chromatograph, to assure that the oxygen levels have been reduced to less than 30% prior to venting the chamber to the VES. Flow through experiments utilizing the VES "real-time" must be limited to 30% O_2. The O_2 sensor will be used to assure that the 30% maximum concentration is not exceeded. Flow-through experiments above 30% O_2 must be re-circulated by the PI-specific hardware within the test chamber. After completion of the experiment run, the test chamber environment must be diluted as described in the above paragraph. If the PI desires levels above this, it must be accomplished through the used of PI hardware such that the 85% limit in the chamber and the 30% limit in the vent system are not exceeded.	A.2.3.4.2, A.2.2.4.2.1

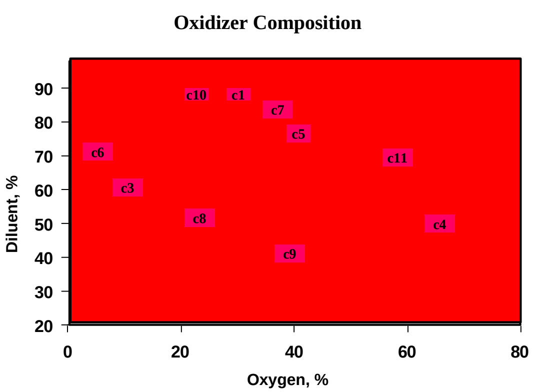


Figure C5a

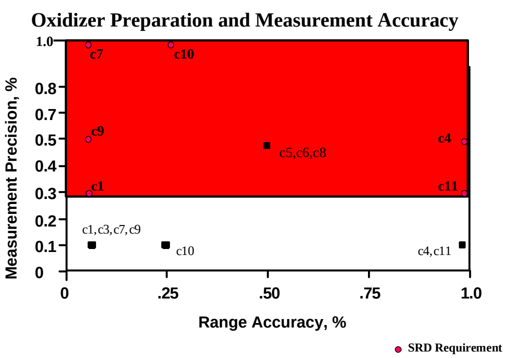


Figure C5b

SRED REQUIREMENT Req. C6 - The FCF shall provide controlled flow of fuel over the volume flow rate range of 0 to 30 cc/sec under standard conditions (i.e., scc/sec) and controlled flow of oxidizer over the volume flow rate range of 0 to 4,000 scc/sec with an accuracy of 10% and a stability of 5% of the set point.	SRED Sec. 3.2.3
ENGINEERING INTERPRETATION FCF shall provide controlled flow of fuel over the volume flow rate range of 0 to 30 cc/sec under standard conditions (i.e., scc/sec) and controlled flow of oxidizer over the volume flow rate range of 0 to 4,000 scc/sec with an accuracy of 10% and a stability of 5% of the set point.	CIR B-Spec Sec. 3.2.1.19, 3.2.1.20
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE The maximum flow of fuel from FCF Fuel/Premixed Fuel Supply Manifold is 33.3 cc/sec (2 SLM). The maximum oxidizer/diluent flow rate is 1500 cc/sec (90 SLM). There are three methods by which flow can be provided within the combustion chamber: 1) flow though with dynamic venting, 2) internal re-circulation, and 3) circulation through the exhaust vent package. 1) FCF is capable of supplying a continuous oxidizer/diluent flow of 90SLM to the chamber while dynamically venting. The design of the PI-specific Hardware will determine/control the linear speed and direction. If the PI-specific Hardware has a flow duct maximum cross section of $30cm^2$ for c3 and $75cm^2$ for c4 and c11 the requirements can be met. 2) PI-specific Hardware (fans or other devices) within the chamber can provide the necessary flow speed and direction by internal re-circulation. 3) Although not provided as a standard service, there is the capability for FCF to circulate flow from the chamber through the exhaust vent package and back into the chamber. FCF is capable of flowing 20 SLM through this system.	BSD Sec. A.2.3.4.2, A.2.2.4.2.1, A.2.2.4.2.2

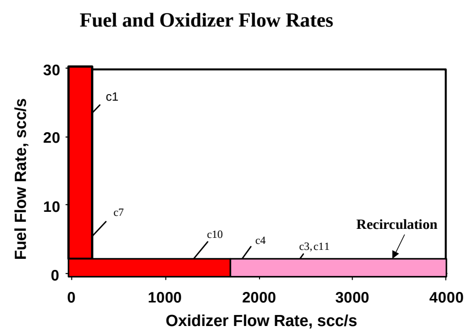

Fuel and Oxidizer Flow Rates
Fuel Flow Rate, scc/s
Oxidizer Flow Rate, scc/s
0
10
20
30
0
1000
2000
3000
4000
c1
c7
c10
c4
c3, c11
Recirculation

Figure C6

SRED REQUIREMENT	SRED Sec.
Req. C7 - The FCF shall provide all necessary support (e. g., data storage, fuel, oxidizer, and diluent storage and distribution, combustion product collection and disposal) to accomplish experiments having ranges of duration and repetition represented by the basis experiments described in this document. Requirements are shown in Figure C7.	3.2.4
ENGINEERING INTERPRETATION	CIR B-Spec Sec.
FCF shall provide all necessary support (e.g., data storage, fuel, oxidizer, and diluent storage and distribution, combustion product collection and disposal) to accomplish experiments having ranges of duration and repetition represented by the basis experiments described in this document. Test times in Figure C7 include set-up time.	3.2.1.21, 3.2.1.22
ENGINEERING RESPONSE	BSD Sec.
COMPLY The FCF FOMA can provide the necessary bottles and filters to accomplish most of the basis experiments described in this document. Flow-through, re-circulated flow-through, or partial pressure environment techniques can be used to accomplish test duration requirements. All diagnostic imaging packages can acquire data for a minimum of 20 minutes at maximum frame-rate/resolution. This should support any single test run. Data will have to be downlinked from ISS when total run time approaches 20 minutes at maximum acquisition rates to avoid storage overflow and loss of data.	A.2.2.4.2.1, A.2.2.5.1

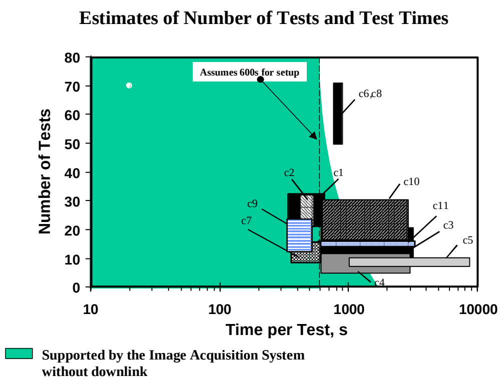

Estimates of Number of Tests and Test Times
Assumes 600s for setup
Number of Tests
80
70
60
50
40
30
20
10
0
10
100
1000
10000
Time per Test, s
c6,c8
c2
c1
c10
c9
c7
c11
c3
c5
c4
Supported by the Image Acquisition System without downlink

Figure C7

SRED REQUIREMENT	SRED Sec.
Req. C8 - The FCF shall provide imaging systems, illumination sources, power, control, and data acquisition capabilities for imaging in the visible spectrum (400-700 nm). The imaging systems shall accommodate the envelopes of parameters defined for the basis experiments. Framing rates to 100/ sec are required. Requirements are shown in Figure C8a- c. When the visible sensor is used primarily as a temperature, velocity, or soot measurement sensor, additional requirements apply (see Requirements C12, Temperature Field Measurements, C14, Chemical Composition and Soot Measurements, and C17, Full Field Velocity Imaging).	3.3.1
ENGINEERING INTERPRETATION	CIR B-Spec Sec.
There is an intricate interacting of imaging requirements over the range of Basis Experiments. For full support of science, various combinations of imaging systems are required in various geometric relationships. The “envelopes” of requirements are covered as indicated in the following compliance responses. In some instances a specific requirement of a specific experiment may not be met, even though the requirement “envelope” has been covered, because the imaging system covering that “envelope” is not suitable in other aspects for application in the specific experiment diagnostic suite. These exceptions, where known, are identified both in the following Engineering Responses and in the Combustion Science Basis Experiments Compliance Appendix. FCF shall provide imaging systems, illumination sources, power, control and data acquisition capabilities for imaging in the visible spectrum. The requirement includes the implementation of color, monochrome and low light level imaging systems. The resolution requirement is interpreted as the smallest object size that must be resolved at a signal level that is no less than 50% of maximum. Maximum resolution is required at the minimum FOV; minimum resolution applies at the maximum FOV. The FOV requirements represent minimum acceptable values and apply to a plane that contains the combustion chamber longitudinal axis. Depth of field is the range of motion in the depth direction, in object space, where defocus blur is no larger than the Nyquist limit and is determined at full aperture.	3.2.1.23, 3.2.1.23.1, 3.2.1.23.2, 3.2.1.23.3, 3.2.1.23.4

ENGINEERING RESPONSE	BSD Sec.
PARTLY COMPLY The CIR provides five (5) Imaging Packages that operate in the visible spectrum: a Color Package; a High Frame-rate/ High-resolution (HFR/HR) Package; a High Bit Depth Multispectral (HiBMs) Package; a Low Light Level UV (LLL-UV) Package, and a Low Light Level Near-IR (LLL-IR) Package. Color orthogonal imaging is not planned; orthogonal imaging can be obtained by mixing diagnostic packages; for example, the Color Package could be used for one view and the HFR/HR Package for an orthogonal view. The HFR/HR and HiBMs Packages are telecentric in object space, which will eliminate object size (magnification) change when the object distance is changing and will accommodate requirements such as the case of a droplet drifting perpendicular to the image plane. <u>Frame-rate vs. Resolution Chart</u> (C8a): 82% Compliance. All requirements for frame-rate can be met by the HFR/HR Package in HFR mode. 82% of the experiments are fully covered for resolution in the HR mode (exceptions are experiments c6 and c8). The accuracy requirements of c6 and c8 will be satisfied. The c8 SRD resolution/frame-rate requirement (50 μm resolution in color at 100 fps and 50 mm FOV) cannot be met as stated. The c8 resolution could be met using the Color at 30 fps with a 50 mm FOV PI provided lens or the c8 resolution and frame-rate could be met using HFR/HR at 100 fps by reducing the FOV to 25 mm with a PI provided lens. The c8 SRD requirement for 1% accuracy in droplet diameter measurement is not met for droplets below 1.8 mm diameter (HFR/HR covers 64% of the droplet diameter range with the required accuracy). <u>Field of View vs. Depth of Field Chart</u> (C8b): Full Compliance. All field of view requirements can be met by the Color Package. The depth of field at maximum resolution and aperture in the Color Package is less than all experiment requirements and can be increased without limit by reducing the aperture; therefore it is assumed that all experiment requirements are met. <u>Lateral Field of View vs. Axial Field of View Chart</u> (C8c): Full Compliance. Both field of view requirements are met by the Color Package. The HFR/HR Package can be used to meet resolution requirements of the c6 SRD; however, the instantaneous FOV and tracking FOV requirements are not satisfied by HFR. The use of HiBMs for supplemental wide field imaging is a possibility. <u>Color Package</u> typical operation is in full-frame mode at a maximum frame-rate of 30 fps. The FOV range of this package is 90-350 mm square with a 2X zoom capability by means of a motorized relay lens module and two manual change-out objective modules. Resolution values range from 2.8 to 0.7 lp/mm as a function of the package zoom position. Spectral response is over the visible spectrum from 400 nm to 700 nm. Auto-exposure is available by control of shutter and/or gain. Typical run time is 25 minutes at 30 fps.	A.2.2.5, A.2.2.5.3, A.2.2.5.2, A.2.2.5.1, A.2.2.5.4

<u>High Frame-rate/High-resolution Package</u> contains a monochrome imager operating at 8 bit depth; it will accept a tunable spectral filter and has internal object tracking capability. The high frame-rate mode requires 2x2 pixel binning and provides a frame-rate of 110 fps at 12 lp/mm resolution. The high-resolution mode is full-frame and provides a frame-rate of 30 fps at 20 lp/mm. The package has a telecentric imaging system with an instantaneous FOV of 9.3 mm, which will track over a 46 mm diameter total field. The package is also capable of performing auto-focusing over a depth range of 30 mm. Auto-exposure is available by control of shutter and/or gain. Typical run time is 20 minutes in either mode of operation. <u>HiBMs Package</u> is a 12-bit depth monochrome imager that can operate at 15 fps with full resolution giving 20 minutes run time or at 30 fps in binned mode with 40 minutes run time. The optical system is telecentric with 50 and 80 mm diameter FOVs and corresponding maximum resolution levels of 10 and 5 lp/mm, depending upon the lens configuration selection. This package contains a removable liquid crystal filter operating over a wavelength range of 650 to 1050 nm, tunable to single wavelengths with 10 nm bandwidth. 200 ms are required for a filter state change. Auto-exposure is available by control of iris, shutter and/or gain. <u>LLL-UV Package</u> contains an intensified monochrome imager; typical operation is 2x2 binned mode up to 60 fps with 8 bit depth; full-frame mode at 30 fps is also available, but will not benefit from the boost in sensitivity that pixel binning provides. Spectral response is from 220 nm to 850 nm using a Gen II intensifier. Typical sensitivity is $1x10^{-7}$ ft-candles in full-frame mode, and $2x10^{-7}$ ft-candles in binned mode. The FOV is manually selectable between 42 mm and 100 mm square, depending upon the objective lens configuration. Maximum resolution values, range from 4.3 lp/mm in binned mode to 6.7 lp/mm in full-frame mode. Auto-exposure is available by control of shutter and/or gain. Typical run time is 40 minutes at 60 fps and 20 minutes at 30 fps. <u>LLL-IR Package</u> contains an intensified monochrome imager; typical operation is in 2x2 binned mode up to 60 fps with 8 bit depth; full frame mode at 30 fps is also available, but will not benefit from the boost in sensitivity that pixel binning provides. Spectral response is from 400 nm to 900 nm using a Gen III Ultra Extended Blue intensifier. Typical sensitivity is $1x10^{-7}$ ft-candles in full-frame mode, and $2x10^{-7}$ ft-candles in 2x2 binned mode. The FOV range of this package is 45-180 mm square with a 2X zoom capability by means of a motorized relay lens module and two manual change-out objective modules. Maximum resolution values, range from 4.3 lp/mm in binned mode to 6.8 lp/mm in full-frame mode. Typical run time is 40 minutes at 60 fps and 20 minutes at 30 fps.	

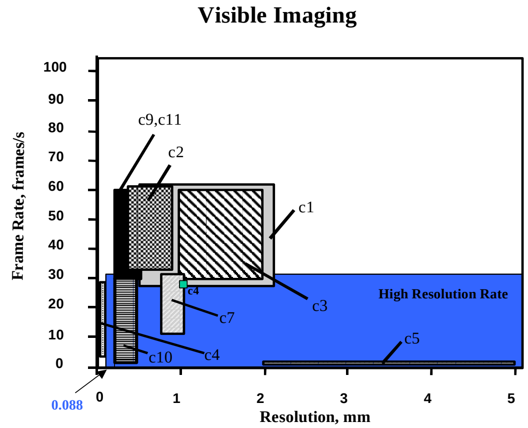


Figure C8a- **Color Camera Package**

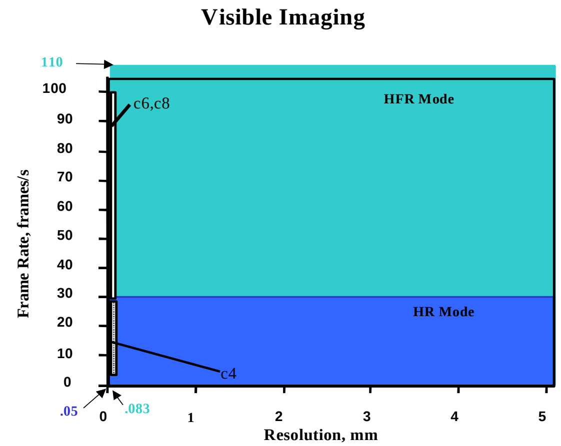


Figure C8a - **HFR/HR Package**

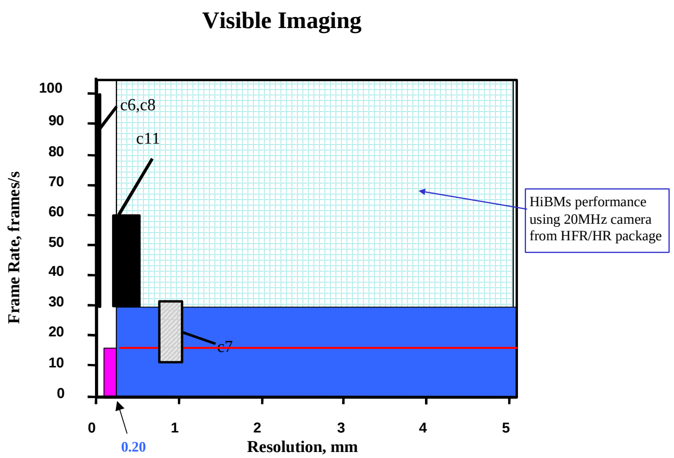


Figure C8a- **HiBMs Package**

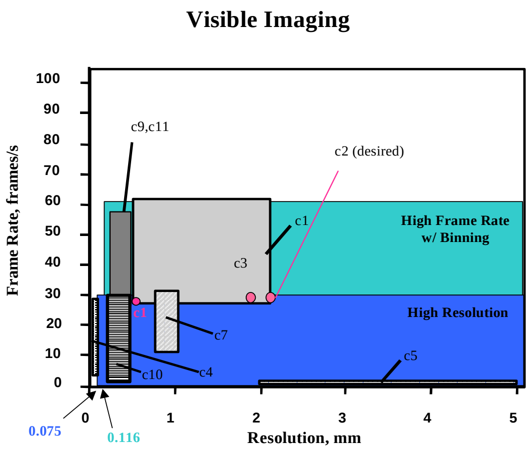


Figure C8a - **Low Light Level Packages**

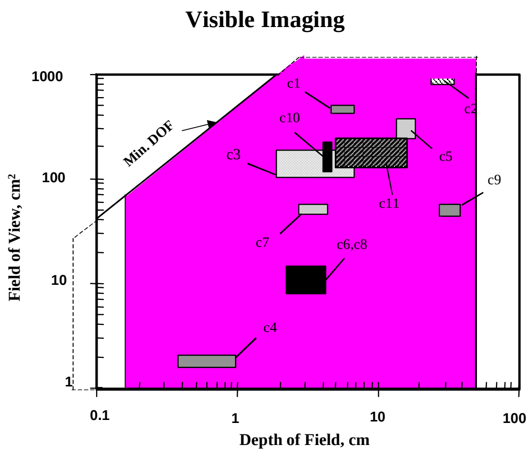


Figure C8b - **Color Camera Package**

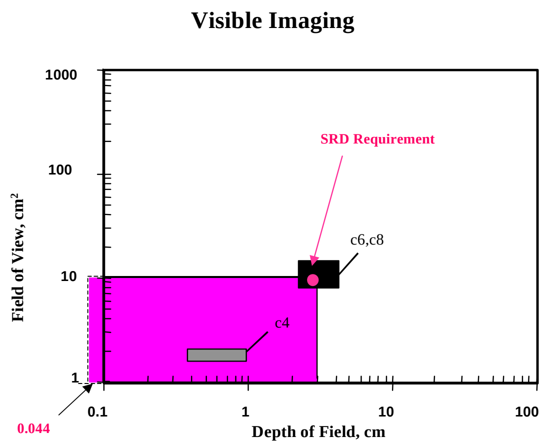


Figure C8b - **HFR/HR Package**

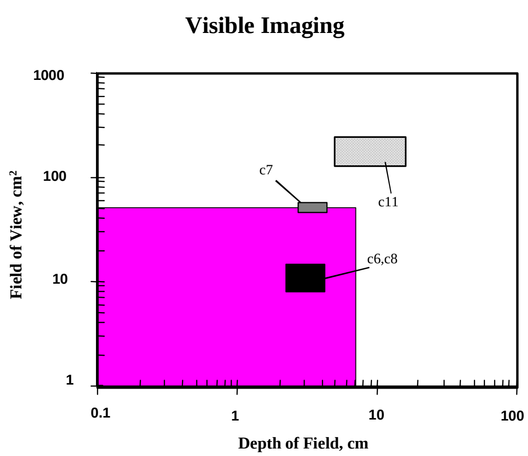


Figure C8b - **HiBMs Package**

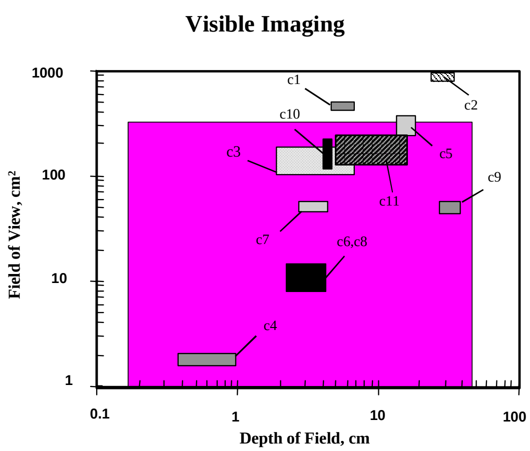


Figure C8b – **Low Light Level Packages**

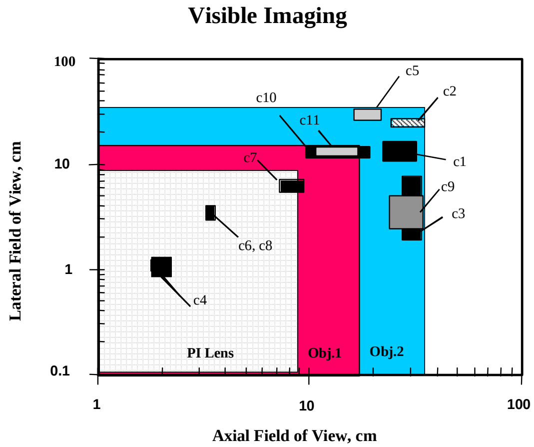


Figure C8c- **Color Camera Package**

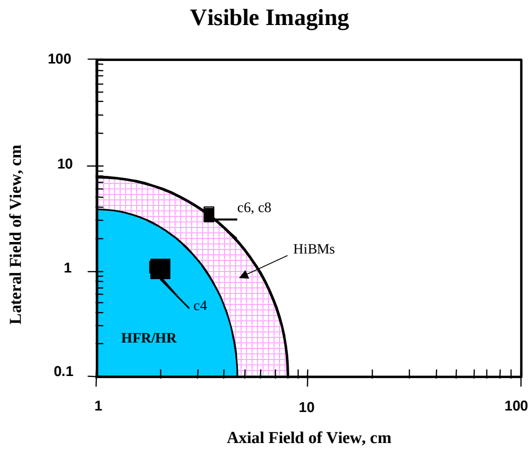


Figure C8c- **HFR/HR Package**

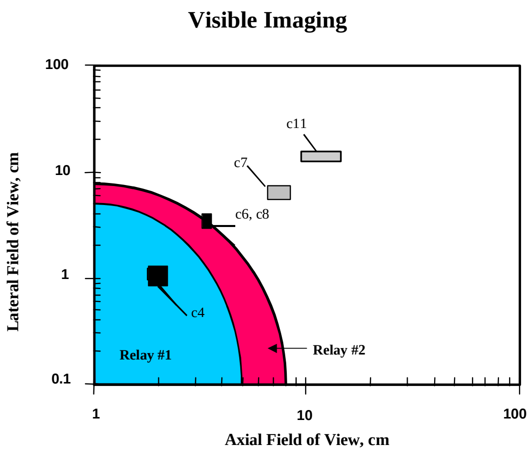


Figure C8c- **HiBMs Package**

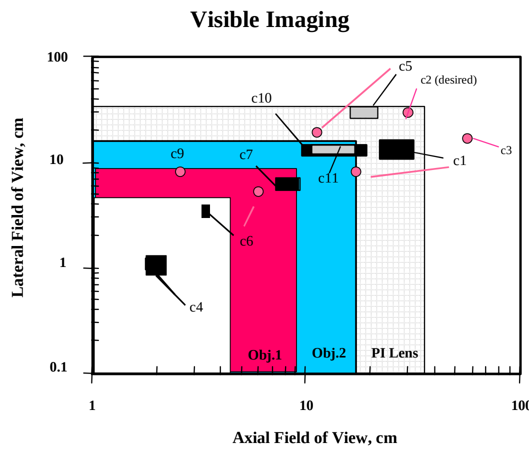


Figure C8c-**Low Light Level IR Camera Package**

SRED REQUIREMENT Req. C9 - The FCF shall provide imaging systems, power, control and data acquisition capabilities to image flames and surfaces in the infrared spectrum in the wavelength range of 1,000 to 5,000 nm and 8,000 to 14,000 nm. Framing rates to 60/sec are required. Requirements are shown in Figure C9a-c. When the infrared imager is used primarily as a temperature sensor, additional requirements apply (see Requirements C11 and C12, Temperature Measurements).	SRED Sec. 3.3.1
ENGINEERING INTERPRETATION FCF shall provide imaging systems, power, control and data acquisition capabilities for imaging in the infrared region of the spectrum. The resolution requirement is interpreted as the smallest object size that must be resolved at a signal level, which is no less than 50% of maximum. Maximum resolution is required at minimum FOV; minimum resolution applies at maximum FOV. The FOV requirements represent minimum acceptable values and apply to a plane that contains the combustion chamber longitudinal axis. Depth of field is the range of motion in the depth direction in object space where defocus blur is no larger than the Nyquist limit and is determined at full aperture.	CIR B-Spec Sec. 3.2.1.23, 3.2.1.23.5
ENGINEERING RESPONSE PARTLY COMPLY WITH PI HARDWARE FCF will provide a Mid-IR camera package operating at 30 or 60 fps. Its spectral response is from 1 to 5 microns and it provides a resolution of 0.9 lp/mm. The package maximum FOV is 183mm X 138mm. Longer wavelength detection (8 to 14 microns) can be accomplished with a PI provided Long-IR camera package. This package can be positioned in any of the CIR UML locations. FCF will provide a chamber window with infrared material to support transmission at these wavelengths. In addition, FCF will provide electrical and mechanical interfaces and cooling capabilities at the CIR UML interfaces (see FCF-DOC-003 Rev. A/CIR BSD for interface specifications), as well as the imaging acquisition capabilities provided in the Common IPSU. It has been assumed that experiment c3 will use Long-IR. There are no current SRD requirements for Mid-IR imaging in experiments c1 and c2.	BSD Sec. A.2.2.5.5, A.2.2.5

C9 ENGINEERING RESPONSE (continued) Note: Some of the visible imaging cameras have spectral sensitivity to 1050 nm and may have application to this requirement. Frame-rate vs. Resolution Chart (C9a): 75% Compliance. All requirements for frame-rate are met by the Mid-IR Package. The resolution requirement of experiment c4 can be met by insertion of a PI provided lens into the imaging package. Achieving required resolution and FOV simultaneously for experiment c10 requires a PI provided imager with a pixel array having 8x more pixels (may not be available with current technology in an acceptable package size). Field of View vs. Depth of Field Chart (C9b): Full Compliance. The field of view requirements for experiments c4 and c10 are met. The depth of field at maximum resolution and aperture in the Mid-IR Package is less than the experiment requirements and can be increased without limit by reducing aperture; therefore it is assumed that this experiment requirement is met. Lateral Field of View vs. Axial Field of View Chart (C9c): Full Compliance. The field of view requirements for experiments c4 and c10 are met by the Mid-IR Package.	

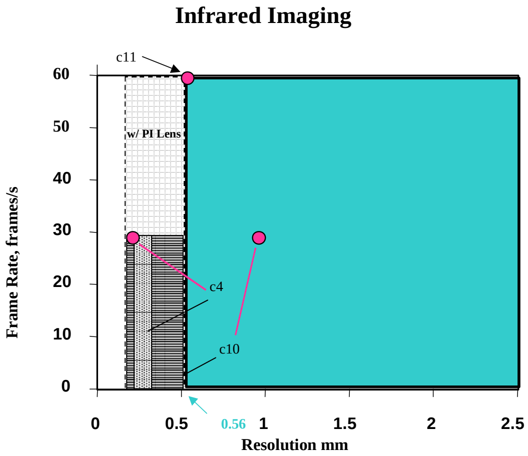


Figure C9a- **Mid-IR Camera Package**

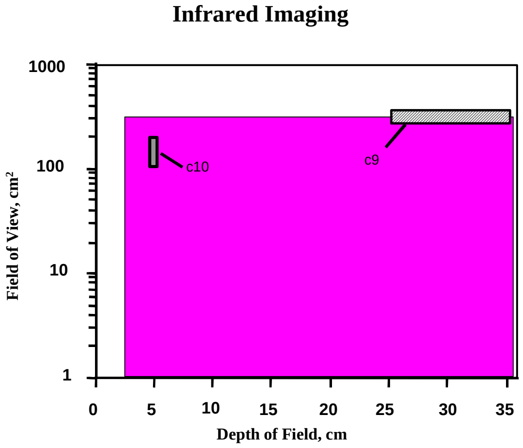


Figure C9b- **Mid-IR Camera Package**

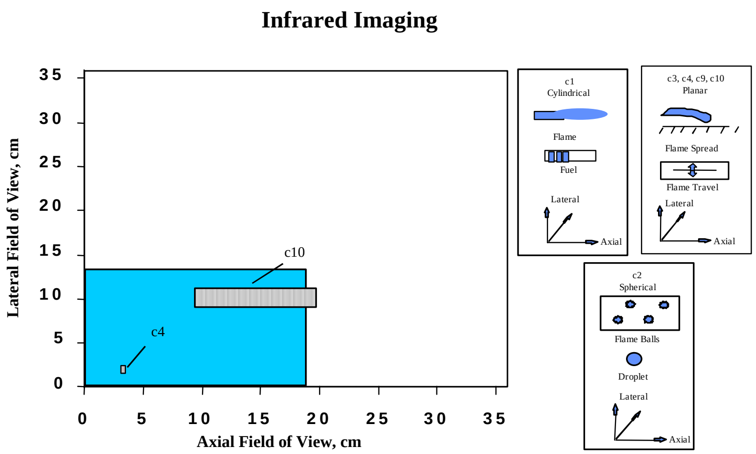


Figure C9c- **Mid-IR Camera Package**

SRED REQUIREMENT Req. C10 - The FCF shall provide imaging systems, power, control and data acquisition capabilities for imaging in the ultraviolet spectrum (nominally 250 to 400 nm). Framing rates to 100/sec are required. Requirements are shown in Figures C10a-c.	SRED Sec. 3.3.1
ENGINEERING INTERPRETATION FCF shall provide imaging systems, power, control and data acquisition capabilities for imaging in the ultraviolet. Frame-rates of up to 100 fps are required. It is understood that high sensitivity sensors are needed for flame imaging. The resolution requirement is interpreted as the smallest object size that must be resolved at a signal level that is no less than 50% of maximum. Maximum resolution is required at minimum FOV; minimum resolution applies at maximum FOV. The FOV requirements represent minimum acceptable values and apply to a plane that contains the combustion chamber longitudinal axis. Depth of field is the range of motion in the depth direction in object space where defocus blur is no larger than the Nyquist limit and is determined at full aperture.	CIR B-Spec Sec. 3.2.1.23, 3.2.1.23.6
ENGINEERING RESPONSE PARTLY COMPLY FCF will provide an LLL-UV Package that contains an intensified monochrome imager; typical operation is 2x2 binned mode up to 60 fps with 8 bit depth; full-frame mode at 30 fps is also available, but will not benefit from the boost in sensitivity that pixel binning provides. Spectral response is from 220 nm to 850 nm using a Gen II intensifier. Typical sensitivity is 1×10^{-7} ft-candles in full-frame mode, and 2×10^{-7} ft-candles in binned mode. The FOV is manually selectable between 42 mm and 100 mm square, depending upon the objective lens configuration. Maximum resolution values, range from 4.3 lp/mm in binned mode to 6.7 lp/mm in full-frame mode. Auto-exposure is available by control of shutter and/or gain. Typical run time is 40 minutes at 60 fps and 20 minutes at 30 fps. Provision for spectral filtering (at 310 nm, for example) is provided. Frame-rate vs. Resolution Chart (C10a): 88% Compliance. The high range of the frame-rate requirements in experiments c2, c6 and c8 are not met by the LLL-UV Package. (It should be noted that this requirement is fully met in the present SRDs for these experiments.) The experiments are fully covered for resolution by the LLL-UV Package.	BSD Sec. A.2.2.5.4

Field of View vs. Depth of Field Chart (C10b): 94% Compliance. The high range of the field of view requirements in experiment c10 is not met by the LLL-UV Package. All other field of view requirements are met by the LLL-UV Package. The depth of field at maximum resolution and aperture in the LLL-UV Package is less than all experiment requirements and can be increased without limit by reducing aperture; therefore it is assumed that all experiment requirements are met. Lateral Field of View vs. Axial Field of View Chart (C10c): 93% Compliance. The high range of the field of view requirements in experiment c10 is not met by the LLL-UV Package. All other field of view requirements are met by the LLL-UV Package. The wider field of view of experiment c10 can be met by insertion of a PI provided lens into the imaging package.	

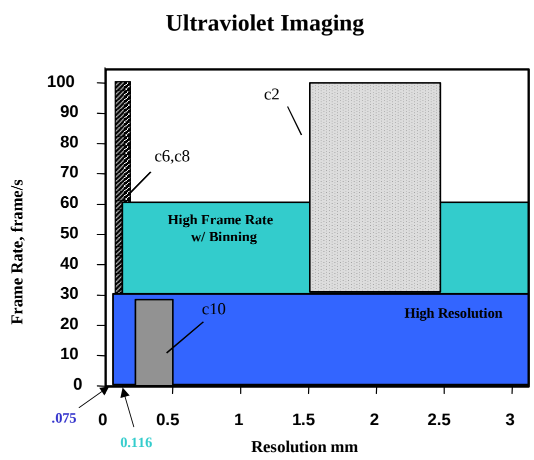


Figure C10a-**Low Light Level UV Camera Package**

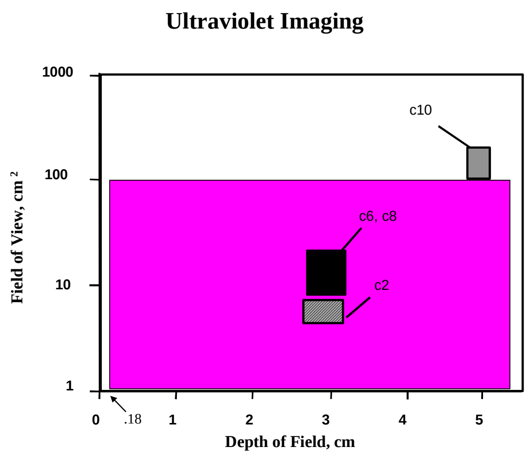


Figure C10b-**Low Light Level UV Camera Package**

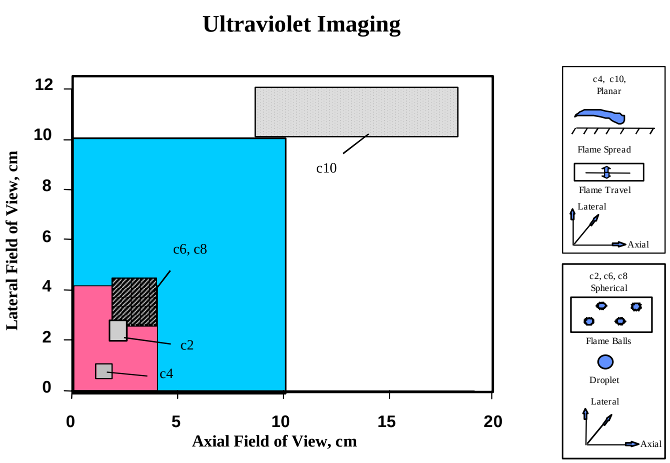


Figure C10c-**Low Light Level UV Camera Package**

SRED REQUIREMENT Req. C11 - FCF shall provide power, control and data acquisition capabilities for making multi-point temperature measurements in the gaseous and condensed phases during the course of experiment operations. Up to 12 temperature measurements in the gas phase and up to 20 temperature measurements in the condensed phase are required. Measurements shall be sampled at selectable rates to 1,000 samples per second in the gas phase and to 30 samples per second in the condensed phase. The temperatures in the gas phase range from 280 to 2,000 K and, in the condensed phase, range from 200 to 1,100 K. Requirements are shown in Figures C11a-d.	SRED Sec. 3.3.2
ENGINEERING INTERPRETATION FCF shall provide power, control and data acquisition capabilities for making multi-point temperature measurements in the gaseous and condensed phases during the course of experiment operations. Up to 12 temperature measurements in the gas phase and up to 20 temperature measurements in the condensed phase are required. Measurements shall be sampled at selectable rates to 1,000 samples per second in the gas phase and to 30 samples per second in the condensed phase. The temperatures in the gas phase range from 280 to 2,000 K and, in the condensed phase, range from 200 to 1,100 K.	CIR B-Spec Sec. 3.2.1.24
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE This requirement is to be implemented as part of the PI-specific hardware. Electrical feedthrus are provided in the instrumentation ring; PI provided signal conditioning could be done in the PI Electronics Enclosure; discrete signals can be sent directly to the IOP for acquisition and storage. Electrical and mechanical interface specifications are provided for the interface resource ring feedthrus.	BSD Sec. A.2.2.4.1, 5.2.4.1

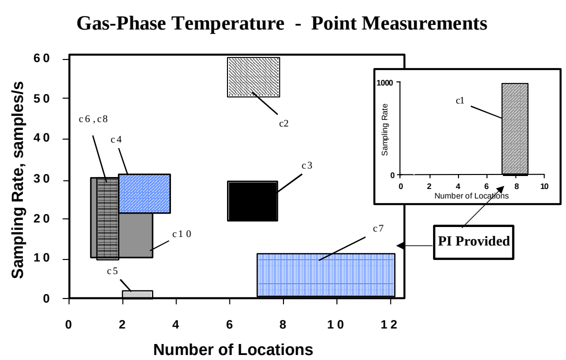


Figure C11a

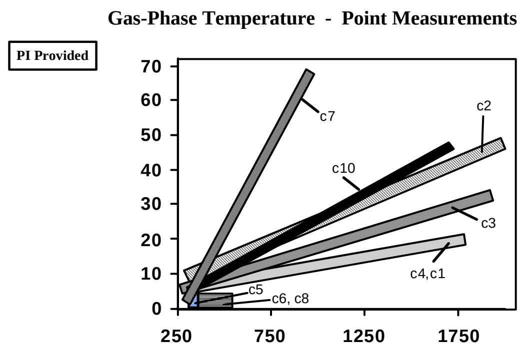


Figure C11b

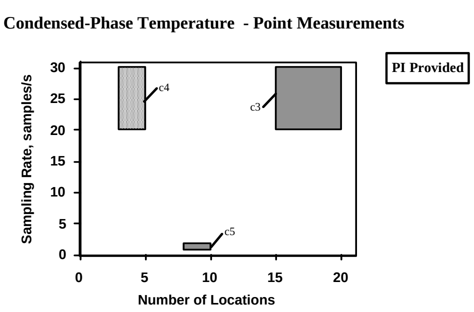


Figure C11c

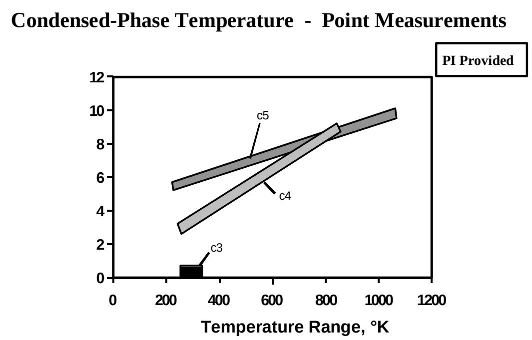


Figure C11d

SRED REQUIREMENT Req. C12 - The FCF shall provide power, control and data acquisition capabilities for measuring temperature fields in the gaseous and condensed phases during the combustion experiment operations. Temperature fields may span the range 280 to 2,000 K in the gas phase and 260 to 1300 K in the condensed phase. Sample rate shall be selectable to at least 60 samples/second. Requirements are shown in Figures C12a-f.	SRED Sec. 3.3.2
ENGINEERING INTERPRETATION The FCF shall provide power, control and data acquisition capabilities for measuring temperature fields in the gaseous and condensed phases during combustion experiment operations. Temperature fields may span the range 280 to 2,000 K in the gas phase and 260 to 1300 K in the condensed phase. Sample rates shall be selectable to at least 60 samples/second. The resolution requirement is interpreted as the smallest object size that must be resolved at a signal level that is no less than 50% of maximum. Maximum resolution is required at minimum FOV; minimum resolution applies at maximum FOV. The FOV requirements represent minimum acceptable values and apply to a plane that contains the combustion chamber longitudinal axis. It is assumed that sample rate is the rate at which full fields are to be recorded (analogous to frame-rate).	CIR B-Spec Sec. 3.2.1.26, 3.2.1.27
ENGINEERING RESPONSE PARTLY COMPLY WITH PI HARDWARE The FCF provides temperature field measurement capability by means of imagery using the Mid-IR Package. The spectral range is 1000 to 5000 nm. This package covers a black body equivalent temperature range of 263 to 1773 K with 2% accuracy. The Mid-IR Package can operate at 60 fps with a FOV of 183 mm x 138 mm and a resolution of 0.9 lp/mm. The design includes a provision for selective wavelength filtering. Longer wavelength detection (8 to 14 microns) can be accomplished with a PI provided Long-IR camera package. This package can be positioned in any of the CIR UML locations. FCF provides a chamber window with infrared material to support transmission at these wavelengths. In addition, FCF will provide electrical and mechanical interfaces and cooling capabilities at the CIR UML interfaces (see FCF-DOC-003 Rev. A/CIR BSD for interface specifications), as well as the imaging acquisition capabilities provided in the Common IPSU.	BSD Sec. A.2.2.5.5, A.2.2.5

C12 ENGINEERING RESPONSE (continued)	
Sampling Rate vs. Spatial Resolution Chart (C12a), Temperature Resolution vs. Temperature Range Chart (C12b), and Lateral Field of View vs. Axial Field of View Chart (C12c): Full Compliance. These requirements are implemented as part of the PI-specific Hardware. Packages can be positioned at any of the CIR UML locations. FCF provides chamber windows that support IR transmission. In addition, FCF will provide electrical and mechanical interfaces and cooling capabilities at the CIR UML interfaces (see FCF-DOC-003 Rev. A/CIR BSD for interface specifications), as well as the imaging acquisition capabilities provided in the Image Processing Package (IPP). For requirements C12d-C12f it is assumed that experiment c3 requires a Long-IR imager. Sampling Rate vs. Spatial Resolution Chart (C12d): 76% Compliance. The requirements for sampling rate are met by the Mid-IR Package. PI-provided imaging lenses would meet the resolution requirements. Note, however, that meeting Resolution and FOV for these experiments simultaneously requires imagers with pixel arrays having more pixels. The alternative imagers would be PI-provided; higher resolution imagers may not be available with current Mid-IR technology in an acceptable package size. With FOV satisfied, the Mid-IR Package provides 24% and 81% of the required spatial resolution for experiments c10 and c11 respectively. Temperature Resolution vs. Temperature Range Chart (C12e): 91% Compliance. The Temperature Resolution requirement for experiment c11 is met by the Mid-IR Package; for c10 the requirement is for 1.25% accuracy. The Mid-IR Package provides 2% accuracy. Temperature Range requirements are met. Lateral Field of View vs. Axial Field of View Chart (C12f): Full Compliance. The current Field of View requirements are fully met by the Mid-IR Package.	

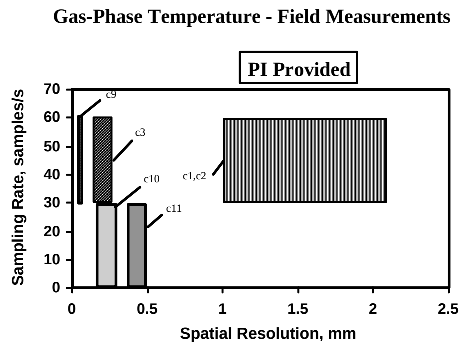


Figure C12a

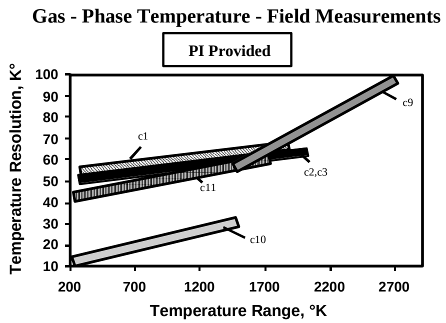


Figure C12b

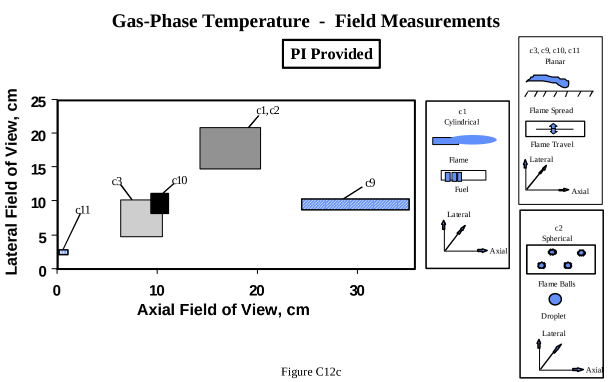


Figure C12c

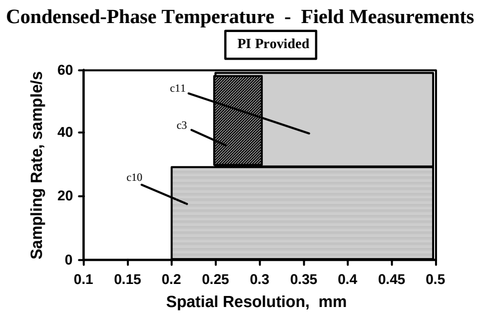


Figure C12d

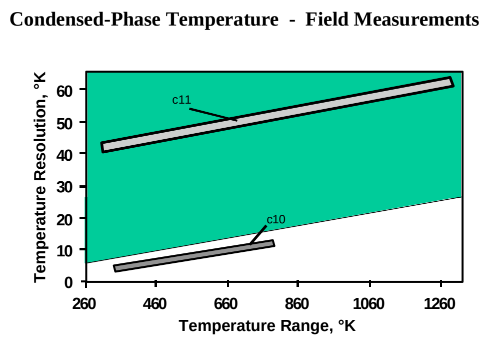


Figure C12e

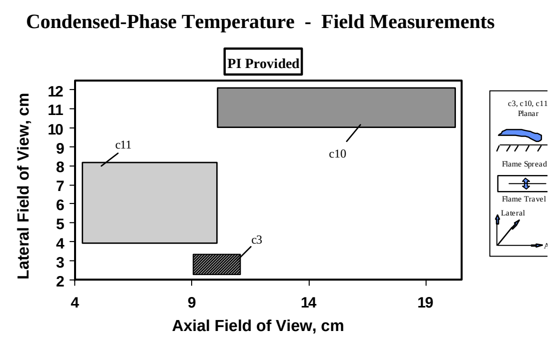


Figure C12f

SRED REQUIREMENT Req. C13 - The FCF shall provide power, control and data acquisition capabilities for measuring pressure of the test section during the course of experiment operations. Pressures may span the range 0 to 10 atm. The FCF shall provide static (less than or equal to 30 Hz) pressure transducers that meet the range and accuracy of the basis experiments. Requirements are shown in Figures C13a-b.	SRED Sec. 3.3.2
ENGINEERING INTERPRETATION FCF shall provide power, control and data acquisition capabilities for measuring the pressure of the test section during the course of experiment operations. Pressures may span the range 0 to 10 atm. FCF shall provide static (less than or equal to 30 Hz) pressure transducers that meet the range and accuracy of the basis experiments.	CIR B-Spec Sec. 3.2.1.28
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE The FCF test chamber MDP is 120 psig (approx. 8 atm); therefore pressure measurements will be available up to this value. The response times for the four (4) pressure transducers are 5K Hz. PI-provided pressure vessels would be instrumented with PI-specific Hardware. Electrical and mechanical interface specifications are provided between the Optics Bench and the PI-specific Electronics Package and for the interface resource ring feedthrus.	BSD Sec. A.2.2.4.1

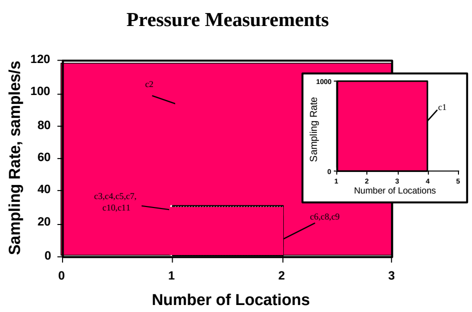


Figure C13a

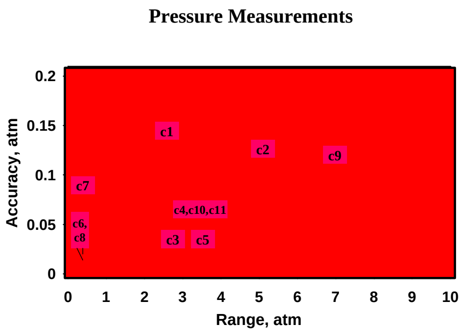


Figure C13b

SRED REQUIREMENT Req. C14 - The FCF shall provide sensor systems, power, control and data acquisition capabilities for measuring chemical composition by gas sampling and gas analysis. The components to be measured are hydrogen, methane, propane, oxygen, nitrogen, carbon monoxide, carbon dioxide, sulfur hexafluoride, and water. The range of required measurements shall be 0.1 to 100 % by volume with an accuracy of 2% of reading. The FCF shall provide power, control and data acquisition capabilities for measuring soot volume fraction, soot temperature, and for collecting soot particles in the test section during a combustion experiment. The requirements are shown in Figures C14a-c.	SRED Sec. 3.3.2
ENGINEERING INTERPRETATION FCF shall provide sensor systems, power, control and data acquisition capabilities for measuring chemical composition by gas sampling and gas analysis. The components to be measured are hydrogen, methane, propane, oxygen, nitrogen, carbon monoxide, carbon dioxide, sulfur hexafluoride, and water. The range of required measurements shall be 0.1 to 100 % by volume with an accuracy of 2% of reading. The FCF shall provide power, control and data acquisition capabilities for measuring soot volume fraction, soot temperature, and for collecting soot particles in the test section during a combustion experiment. The resolution requirement is interpreted as the smallest object size that must be resolved at a signal level that is no less than 50% of maximum. Maximum resolution is required at minimum FOV; minimum resolution applies at maximum FOV. The FOV requirements represent minimum acceptable values and apply to a plane that contains the combustion chamber longitudinal axis.	CIR B-Spec Sec. 3.2.1.29, 3.2.1.30
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE The FCF provides chemical composition capabilities through the implementation of gas chromatography, two-wavelength pyrometry, light absorption diagnostic system and PI-provided hardware for collection of soot particles. The gas chromatograph (GC) package has three independent separation columns and uses Helium and Argon carrier gases. The GC can accommodate one check gas for the specific compounds that are expected from the combustion event.	BSD Sec. A.2.2.4.2.2, A.2.2.5.1, A.2.2.5.6

C14 ENGINEERING RESPONSE (continued)	
Two-wavelength pyrometry (soot temperature measurements) and light absorption (soot volume fraction) techniques can be implemented using the same diagnostic package. The HiBMs Package can be programmed to cycle operation from soot temperature measurement (STM) mode to soot volume fraction (SFV) mode. The optical system is telecentric with 50 and 80 mm diameter FOVs and corresponding maximum resolution levels of 10 and 5 lp/mm depending upon lens configuration selection. The HiBMs Package is a 12-bit depth monochrome imager that can operate at 15 fps with full resolution giving 20 minutes run time or at 30 fps in binned mode with 40 minutes run time. The package contains a liquid crystal tunable filter (LCTF) that operates over the wavelength range of 650 to 1050 nm. The unit can be tuned to transmit single wavelengths with a 10 nm bandwidth with 1 nm spectral resolution for the STM mode. 200 ms are required for a filter state change. Auto-exposure is available by control of iris, shutter and/or gain. To provide light absorption data for SVF measurements, the package operates in conjunction with the Illumination Package. The Illumination Package provides a collimated 675 nm peak wavelength laser beam that is 80 mm in diameter that propagates through the flame/soot region. Number of Samples vs. Number of Locations Chart (C14a): Full Compliance. Provided by PI hardware. Electrical and mechanical interface specifications are provided between the Optics Bench and the PI-specific Electronics Package and for the interface resource ring feedthrus. Lateral Resolution vs. Axial Resolution Chart (C14b): Full Compliance. The HiBMs Package with 50 mm FOV optics meets all resolution requirements. Lateral Field of View vs. Axial Field of View Chart (C14c): Full Compliance. The current c7 Axial Field of View SRD requirement is being met.	

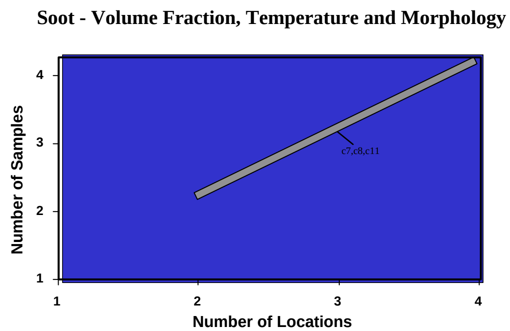


Figure C14a

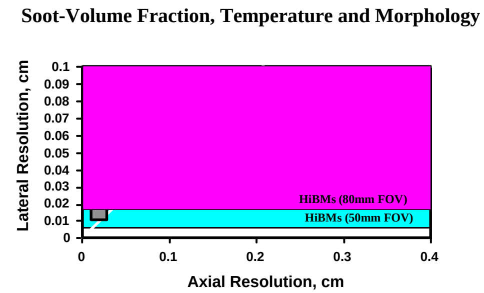


Figure C14b

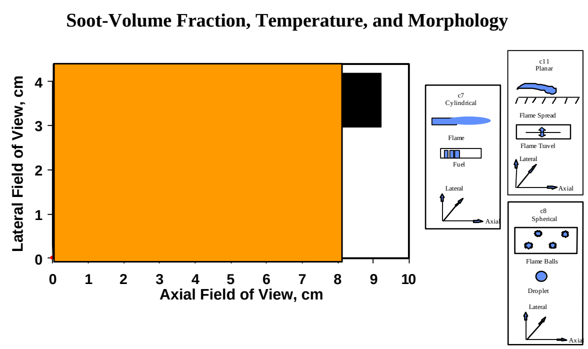


Figure C14c

SRED REQUIREMENT	SRED Sec.
Req. C15 - The FCF shall provide power, control and data acquisition capabilities for measuring radiated energy in the spectral range 200 to 40,000 nm during the combustion experiment. Requirements are shown in Figure C15.	3.3.2
ENGINEERING INTERPRETATION FCF shall provide power, control and data acquisition capabilities for measuring radiated energy in the spectral range 200 to 40,000 nm during the combustion experiment.	CIR B-Spec Sec. 3.2.1.31
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE PI-specific Hardware provides radiometric measurement. Sufficient electrical feedthrus are provided in the instrumentation ring; PI-provided signal conditioning can be done in the PI Electronics Enclosure; discrete signals can be sent directly to the IOP for acquisition and storage. Electrical and mechanical interface specifications are provided for the interface resource ring feedthrus.	BSD Sec. A.2.2.4.1, 5.2.4.1

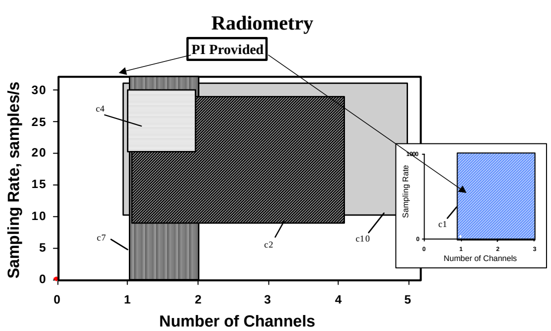


Figure C15

SRED REQUIREMENT	SRED Sec.
Req. C16 - The FCF shall provide power, control and data acquisition capabilities for measurement of gas velocity in the test section over the range of 0.5 to 5,000 cm/sec. Measurements shall be made at selected locations (1 to 20) in the test section and sampled at rates from 2 to 1,000 samples/second. The FCF shall accommodate the exhaust of seeding particles. Requirements are shown in Figures C16a-b.	3.3.3
ENGINEERING INTERPRETATION	CIR B-Spec Sec.
FCF shall provide power, control and data acquisition capabilities for measurement of gas point velocity in the test section over the range of 0.5 to 5,000 cm/sec. Measurements shall be made at selected locations (1 to 20) in the test section and be sampled at rates from 2 to 1,000 samples/second. FCF shall accommodate the exhaust of seeding particles. The high velocities are interpreted as concentrated flows within a test section; for example, that occur near the exit of a gas jet nozzle.	3.2.1.32
ENGINEERING RESPONSE	BSD Sec.
COMPLY WITH PI HARDWARE Gas velocity measurement is provided by PI hardware. Electrical and mechanical interface specifications are provided between the Optics Bench and the PI-specific Electronics Package and for the interface resource ring feedthrus; discrete signals can be sent directly to the IOP for acquisition and storage. The Exhaust Vent absorber filter screens particles down to 40 μm diameter.	A.2.2.4.1, 5.2.4.1, A.2.2.4.2.2

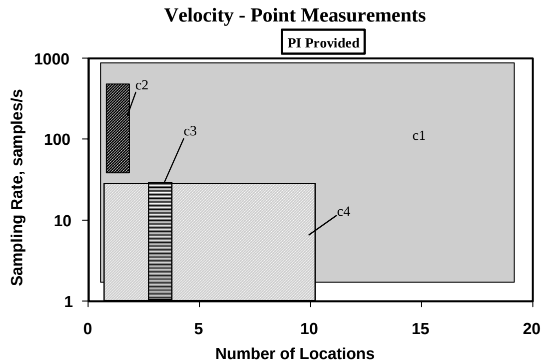


Figure C16a

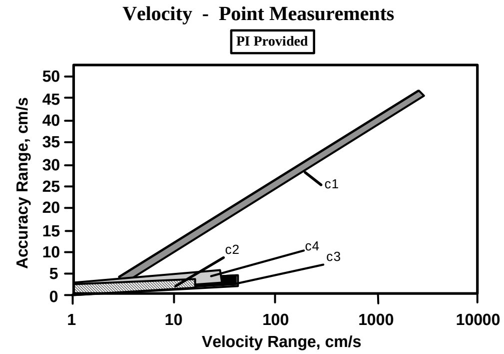


Figure C16b

SRED REQUIREMENT Req. C17 - The FCF shall provide power, control and data acquisition capabilities for full field imaging of velocities in the gas and liquid phases. Measurements shall encompass the required fields of views and be imaged at rates of 30 to 60/ second. The FCF shall accommodate the exhaust of seeding particles. FOV requirements are shown in Fig. C17.	SRED Sec. 3.3.3
ENGINEERING INTERPRETATION FCF shall provide power, control and data acquisition capabilities for full field imaging of velocities in the gas and liquid phases. Measurements shall encompass the required fields of view and be imaged at rates of 30 to 60 per second. FCF shall accommodate the exhaust of seeding particles. The FOV requirements represent minimum acceptable values and apply to a plane that contains the combustion chamber longitudinal axis.	CIR B-Spec Sec. 3.2.1.33
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FCF provides imaging systems such as Color, LLL-IR and LLL-UV Packages to accommodate this technique. Color Package typical operation is in full-frame mode at a maximum frame-rate of 30 fps. The FOV range of this package is 90-350 mm square with a 2X zoom capability by means of a motorized relay lens module and two manual change-out objective modules. Resolution values range from 2.8 to 0.7 lp/mm as a function of the package zoom position. Spectral response is over the visible spectrum from 400 nm to 700 nm. Auto-exposure is available by control of shutter and/or gain. Typical run time is 25 minutes at 30 fps. LLL-UV Package contains an intensified monochrome imager; typical operation is 2x2 binned mode up to 60 fps with 8 bit depth; full-frame mode at 30 fps is also available, but will not benefit from the boost in sensitivity that pixel binning provides. Spectral response is from 220 nm to 850 nm using a Gen II intensifier. Typical sensitivity is 1×10^{-7} ft-candles in full-frame mode, and 2×10^{-7} ft-candles in binned mode. The FOV is manually selectable between 42 mm and 100 mm square, depending upon the objective lens configuration. Maximum resolution values, range from 4.3 lp/mm in binned mode to 6.7 lp/mm in full-frame mode. Auto-exposure is available by control of shutter and/or gain. Typical run time is 40 minutes at 60 fps and 20 minutes at 30 fps.	BSD Sec. A.2.2.5.3, A.2.2.5.4, A.2.2.5.6, A.2.2.4.1, A.2.2.4.2.2

C17 ENGINEERING RESPONSE (continued)	
LLL-IR Package contains an intensified monochrome imager; typical operation is in 2x2 binned mode up to 60 fps with 8 bit depth; full frame mode at 30 fps is also available, but will not benefit from the boost in sensitivity that pixel binning provides. Spectral response is from 400 nm to 900 nm using a Gen III Ultra Extended Blue intensifier. Typical sensitivity is $1x10^{-7}$ ft-candles in full-frame mode, and $2x10^{-7}$ ft-candles in 2x2 binned mode. The FOV range of this package is 45-180 mm square with a 2X zoom capability by means of a motorized relay lens module and two manual change-out objective modules. Maximum resolution values, range from 4.3 lp/mm in binned mode to 6.8 lp/mm in full-frame mode. Typical run time is 40 minutes at 60 fps and 20 minutes at 30 fps. For PIV, the PI either provides modifications for the Illumination Package to accommodate light sheet illumination requirements or provides supplemental illumination hardware. FCF will provide electrical and mechanical interfaces and cooling capabilities at the CIR UML interfaces (see FCF-DOC-003 Rev. A/ CIR BSD for interface specifications), as well as the imaging acquisition capabilities provided in the Image Processing Package (IPP). PI-specific Hardware provides the particle seeding. Electrical and mechanical interface specifications are provided between the Optics Bench and the PI-specific Electronics Package and for the interface resource ring feedthrus. The Exhaust Vent absorber filter screens particles down to 40 μm diameter. Lateral Field of View vs. Axial Field of View Chart (C17): Full Compliance. The field of view requirements are met by the Color, LLL-IR and LLL-UV Packages.	

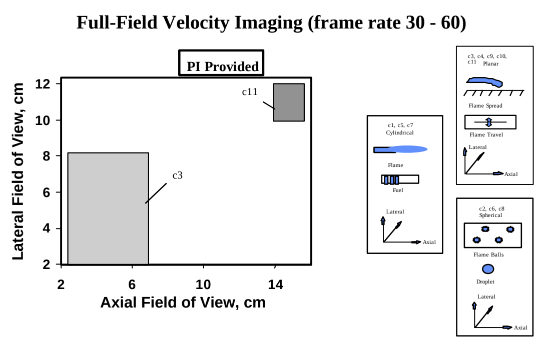

Full-Field Velocity Imaging (frame rate 30 - 60)
PI Provided
Lateral Field of View, cm
Axial Field of View, cm
2
4
6
8
10
12
2
6
10
14
c11
c3
c1, c5, c7
Cylindrical
Flame
Fuel
Lateral
Axial
c3, c4, c9, c10,
c11 Planar
Flame Spread
Flame Travel
Lateral
Axial
c2, c6, c8
Spherical
Flame Balls
Droplet
Lateral
Axial

Figure C17

SRED REQUIREMENT Req. C18 - The FCF shall provide a capability to (typically) monitor residual acceleration and g-jitter over a dynamic range of 10^{-6} to 10^{-2} g/g_0 within the Combustion Facility rack. Specific requirements on frequency and levels will be called out in experiment-specific science requirements, but are expected to fall within the standard parameter range of the Space Acceleration Measurement System (SAMS) accelerometer system. Requirements are shown in Figures C18a-b.	SRED Sec. 3.3.3
ENGINEERING INTERPRETATION FCF shall provide a capability to (typically) monitor residual acceleration and g-jitter over a dynamic range of 10^{-6} to 10^{-2} g/g_0 within the Combustion Integrated Rack. Specific requirements on frequency and levels will be called out in experiment-specific science requirements, but are expected to fall within the standard parameter range of the Space Acceleration Measurement System (SAMS) accelerometer system. It is assumed that accuracy is a percentage.	CIR B-Spec Sec. 3.2.1.34
ENGINEERING RESPONSE COMPLY A Space Acceleration Measurement System (SAMS) head will be installed in the CIR. The SAMS system can measure accelerations in this frequency range better than 10 E-09 g's.	BSD Sec. 5.1.4

Acceleration Measurements

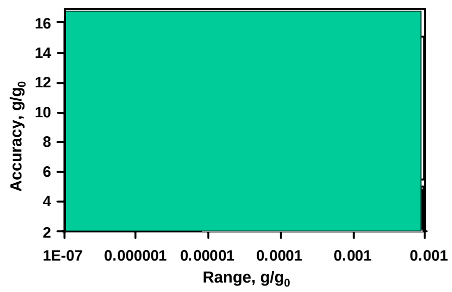


Figure C18a

Acceleration Measurements

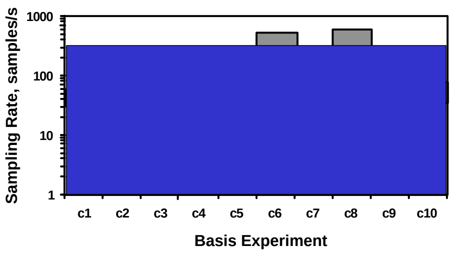


Figure C18b

SRED REQUIREMENT Req. C19 - The FCF shall provide a capability to time-tag all data streams (including video data). A common clock (relatable to International Space Station events) shall be referenced and digital tags shall permit resolution to 1 second for external events and 0.001 second for experiment events.	SRED Sec. 3.4
ENGINEERING INTERPRETATION FCF shall provide a capability to time-tag all data streams (including video data). A common clock (correlated to International Space Station events) shall be referenced and digital tags shall permit resolution to 1 second for external events and 0.001 second for experiment events.	CIR B-Spec Sec. 3.2.1.35
ENGINEERING RESPONSE COMPLY FCF will provide a common clock in the Input/Output Package that will be used to synchronize all other processor clocks at predetermined intervals or upon request. Resolution to 1 second for external events and resolution to 0.001 second for experiment events will be provided.	BSD Sec. 5.2.4

SRED REQUIREMENT	SRED Sec.
Req. C20 - The FCF shall provide, simultaneously, up to eight field measurements and up to 35 single sensor measurements. The FCF shall simultaneously provide the required controls and measurements to operate the PI-specific hardware (required by the science requirements) inside and outside the chamber.	3.4
ENGINEERING INTERPRETATION FCF shall provide, simultaneously, up to eight field measurements and up to 35 single sensor measurements. The FCF shall simultaneously provide the required controls and measurements to operate the PI-specific hardware (required by the science requirements) inside and outside the chamber.	CIR B-Spec Sec. 3.2.1.36
ENGINEERING RESPONSE PARTLY COMPLY This requirement implies that the avionics system must be able to handle all of the simultaneous processes (some of which are TBD) necessary to accommodate the basis experiments. This may not be possible without specialized PI-specific hardware to handle field and/or sensor measurements that the FCF standard avionics services are not providing. The CIR IOP and the CIR FOMA Control Unit will have the capability to acquire more than eight field measurements and thirty-five sensor measurements simultaneously, but those measurements will have to meet the data acquisition interface requirements of the facility. A CANbus control interface, Ethernet LAN interface, and analog and discrete I/O channels will be provided by the FCF to operate the PI-specific hardware inside and outside the chamber. Image acquisition capability is limited to four simultaneous imaging systems unless additional IPSU Packages are provided in the SAR.	BSD Sec. A.2.2.7, 5.2.4, A.2.2.7.2, 5.2.5

SRED REQUIREMENT Req. O1 - The FCF mission planning and utilization organization shall provide and schedule PI team access to FCF simulators having sufficient fidelity to aid in both development and verification of PI hardware and operations procedures.	SRED Sec. 4.2
ENGINEERING INTERPRETATION The FCF Increment Management organization shall provide and schedule PI-team access to FCF simulators that have sufficient fidelity to aid in both development and verification of PI hardware and operations procedures.	FCF A-Spec Sec. 3.7.4.3.8
ENGINEERING RESPONSE WILL COMPLY The FCF organization is planning to develop FCF simulators, which can be used by PI hardware development teams for the development of hardware and operations procedures. Final verification of PI hardware will be performed in the FCF Ground Integration Unit.	BSD

SRED REQUIREMENT Req. O2 - The FCF mission planning and utilization organization shall schedule verification activities so that each PI team has time to simulate more than one mission timeline sequence in the Flight-like configuration.	SRED Sec. 4.2
ENGINEERING INTERPRETATION The FCF Increment Management organization shall schedule verification activities so that each PI team has time to simulate more than one mission timeline sequence in the flight-like configuration.	FCF A-Spec Sec. 3.7.4.3.6
ENGINEERING RESPONSE WILL COMPLY The FCF Increment Management organization will work with each PI team to define their hardware and their software verification requirements. The FCF organization and the PI team will document the verification requirements as part of the Interface Control Document development process.	BSD

SRED REQUIREMENT Req. O3 - Calibration, verification, and functional test data shall be made available to the PI team for at least 90 days following completion of the test activities.	SRED Sec. 4.2
ENGINEERING INTERPRETATION Calibration, verification, and functional test data shall be made available to the PI team for at least 90 days following the completion of test activities	FCF A-Spec
ENGINEERING RESPONSE WILL COMPLY The FCF team will provide test reports to the PI team based on the results of any testing performed, and all data will be provided to the PI team	BSD

SRED REQUIREMENT Req. O4 - Functional performance of facility-provided measurement instrumentation as-integrated with PI team provided hardware shall, typically, be verified in-situ and be traceable to certified reference standards (e.g., temperature, pressure, illumination intensity). As an aspect of this requirement, FCF shall have means to periodically re-verify the functional performance of instruments that will remain on-orbit.	SRED Sec. 4.2
ENGINEERING INTERPRETATION Functional performance of facility-provided measurement instrumentation integrated with PI team-provided hardware shall, typically, be verified in-situ and be traceable to certified reference standards (e.g. temperature, pressure, illumination intensity). As an aspect of this requirement, FCF shall have means to periodically re-verify the functional performance of instruments on-orbit.	FCF A-Spec Sec. 3.2.1.1.8
ENGINEERING RESPONSE WILL COMPLY The design of the FCF system will include replaceable transducers (pressure, massflow controllers) so that they can be replaced periodically. Auto-calibration of measurement devices will be included as practical. The Shared Accommodations Rack may accommodate additional capability for calibration of diagnostic devices.	BSD

SRED REQUIREMENT Req. O5 - FCF shall routinely monitor primary environmental parameters (i.e., temperature, pressure, humidity, and acceleration) within each FCF rack and provide that data to the PI teams before, during, and after the mission - as required.	SRED Sec. 4.3
ENGINEERING INTERPRETATION The FCF shall routinely monitor primary environmental parameters (i.e. temperature, pressure, humidity, and acceleration) within each FCF rack and provide that data to the PI teams before, during, and after the mission.	FCF A-Spec Sec. 3.2.1.1.4
ENGINEERING RESPONSE COMPLY The FCF will routinely monitor primary environmental parameters whenever a rack is powered on. This data will be available to all FCF users as part of standard FCF services to the PI teams. Also additional data requirements may be specified by the PI teams and documented in the Integration Agreement. All data that is specified in the Integration Agreement will be made available to the PI.	BSD

SRED REQUIREMENT Req. O6 - FCF shall routinely provide ancillary ISS data to the PI teams including information on crew activities, maneuvers, docking, altitude, attitude, etceteras.	SRED Sec. 4.3
ENGINEERING INTERPRETATION The FCF shall routinely provide ancillary ISS data to the PI teams including information on crew activities, maneuvers, docking, altitude, attitude, etc.	FCF A-Spec
ENGINEERING RESPONSE WILL COMPLY The FCF Increment Management organization will work with each PI team to define their ancillary data requirements, and to document this in the Integration Agreement. All data that is specified in the Integration Agreement will be made available to the PI. Note: during real-time operations, additional information can be provided as long as it is available.	BSD

SRED REQUIREMENT Req. O7 - FCF shall provide near-real-time data down-link and near-real-time command up-link, as specified in the SRD, to permit true telescience.	SRED Sec. 4.3
ENGINEERING INTERPRETATION FCF shall provide a near-real-time data downlink and a near-real-time command uplink, as specified in the SRD, to permit true telescience.	FCF A-Spec Sec. 3.2.1.1.4 L
ENGINEERING RESPONSE MAY NOT COMPLY Depending on the definition of near-real-time command uplink, latencies on the order of 5 to 10 seconds are the best case to be expected. If this is an adequate time, then the system will comply. The FCF and the GRC Telescience Support Center will provide real-time data links within the boundaries of the ISS communication, the data-handling system, and the ISS Ground Segment.	BSD

SRED REQUIREMENT	SRED Sec.
Req. O8 - FCF shall provide reliable capabilities for recording and protecting science data on-orbit. This capability shall include: Adequate computer memory or other storage media to record all required data from one data point of each active experiment in a time tagged format. Ability to down-link recorded data, limited only by ISS communications bandwidth restrictions on FCF. Clear identification of data existing only on-orbit to assure that no data is accidentally "erased". Ability to transfer data to portable media for return to earth via the Space Shuttle or other transport device.	4.3
ENGINEERING INTERPRETATION	FCF A-Spec Sec.
FCF shall provide reliable capabilities for recording and protecting science data on-orbit. This capability shall include: adequate computer memory or other storage media to record all required data from one data point of each active experiment in a time tagged format. Ability to down-link recorded data, limited only by ISS communications bandwidth restrictions on FCF. Clear identification of data existing only on-orbit to assure that no data is accidentally erased. Ability to transfer data to portable media for return to earth via the Space Shuttle or other transport device.	3.2.1.1.4 f, 3.7.3.3.3 b
ENGINEERING RESPONSE	BSD
COMPLY The current FCF system design accommodates the data requirements of first PIs. The Shared Accommodations Rack will provide the growth capability to accommodate future data storage requirements.	

SRED REQUIREMENT	SRED Sec.
Req. O9 - FCF shall monitor all essential ISS, FCF, and PI hardware parameters to identify off nominal conditions and allow initiation of timely corrective actions that protect the science objectives of operating experiments. In particular, the "quality" of data down-link and command up-link shall be frequently verified.	4.3
ENGINEERING INTERPRETATION The FCF will monitor all essential ISS, FCF, and PI hardware parameters to identify off-normal conditions and to allow the initiation of timely corrective actions that protect the science objectives of operating experiments. In particular, the “quality” of data downlink and command uplink shall be frequently verified.	FCF A-Spec Sec. 3.2.1.1.5
ENGINEERING RESPONSE COMPLY The FCF operations team will be on-console whenever the FCF is powered on, and plans on monitoring all essential parameters for off-normal conditions. Whenever off-normal conditions are encountered contingency procedures will be enacted to address the off-normal condition.	BSD

SRED REQUIREMENT Req. O10 - FCF shall provide both local and remotely located PIs with any custom hardware and software required to display sequential data from FCF sensors (e.g., time, temperature) in tabular or graphical form, and to perform simple statistical transformations on that data (e.g., curve fitting).	SRED Sec. 4.3
ENGINEERING INTERPRETATION The FCF shall provide both local and remotely located PIs with any custom hardware and software that is required to display sequential data from FCF sensors (e.g. time, temperature) in tabular or graphical form, and to perform simple statistical transformations on that data (e.g. curve fitting).	FCF A-Spec
ENGINEERING RESPONSE COMPLY The Telescience Support Center will provide PI teams with Telescience Resource Kits (TReK). Capabilities that are provided by TReK include the capability to view telemetry, perform local exception monitoring, local calculations, word processing, file management, local command and control (including scripting), and a local database. Information that is needed to populate a TReK database can be downloaded from a supporting facility (HOSC or Telescience Support Center) database. Mission execution and mission planning tools are also included on a TReK system.	BSD

SRED REQUIREMENT Req. O11 - FCF shall provide both local and remotely located PIs with any custom hardware and software required to display images acquired by FCF.	SRED Sec. 4.3
ENGINEERING INTERPRETATION The FCF shall provide both local and remotely located PIs with any custom hardware and software to display images that are acquired by the FCF.	FCF A-Spec
ENGINEERING RESPONSE WILL COMPLY The FCF Increment Management organization will work with each PI team to define their requirements for image display. The FCF will provide all the hardware and software that is specified in the Integration Agreement.	BSD

SRED REQUIREMENT Req. O12 - FCF shall store on-orbit and subsequently return to the PI team all existing PI-team-provided, experiment-specific equipment, samples, and data utilized or produced during operation of the experiment, per formal pre-flight agreements between FCF and the PI team.	SRED Sec. 4.4
ENGINEERING INTERPRETATION The FCF shall store on-orbit and subsequently return to the PI team all existing PI team-provided, experiment-specific equipment, samples, and data utilized or produced during operation of the experiment, per formal preflight agreements between the FCF and the PI team.	FCF A-Spec
ENGINEERING RESPONSE COMPLY The FCF Increment Management organization will work with each PI team to define their requirements for return of samples and equipment and document those requirements in the Integration Agreement. Before the experiment is flown, detailed procedures will be developed and will specify what is to be done with all hardware and samples. The FCF will return all hardware, samples, and any other equipment that is specified in the Integration Agreement to the PI team.	BSD

SRED REQUIREMENT Req. O13 - FCF shall make available to the PI all relevant data generated during Flight operations.	SRED Sec. 4.4
ENGINEERING INTERPRETATION The FCF will make available to the PI all relevant data generated during Flight operations.	FCF A-Spec Sec. B.2
ENGINEERING RESPONSE COMPLY The FCF Increment Management organization will work with each PI team to define their data requirements, and document this in the Integration Agreement. All data specified in the Integration Agreement will be made available to the PI. Note: during real-time operations, additional information can be provided as long as it is available.	BSD

SRED REQUIREMENT Req. O14 - FCF shall identify and fill (as possible) gaps in the negotiated data due to communications outages or equipment failures.	SRED Sec. 4.4
ENGINEERING INTERPRETATION The FCF shall identify and fill (as possible) gaps in the negotiated data due to communications outages or equipment failures.	FCF A-Spec
ENGINEERING RESPONSE COMPLY The current design of the ISS Ground System and the GRC TSC provides this capability. The Enhanced HOSC System Software at the TSC provides the capability to identify gaps in the data and provides services to acquire the missing data.	BSD

SRED REQUIREMENT Req. O15 - FCF shall provide access to all negotiated data for at least 90 days following completion of on-orbit operations.	SRED Sec. 4.4
ENGINEERING INTERPRETATION The FCF shall provide access to all negotiated data for at least 90 days following completion of on-orbit operations.	FCF A-Spec Sec. B.2
ENGINEERING RESPONSE WILL COMPLY The current plans for the ground system are to provide access to data for at least 90 days, as well as providing the PI with a hard copy of the data (e.g. on CD-ROM).	BSD

SRED REQUIREMENT Req. O16 - FCF shall deliver all negotiated data in hard copied format within 60 days following completion of on orbit operations, and FCF shall have one preferred medium and data format(s) for delivery of hard copies.	SRED Sec. 4.4
ENGINEERING INTERPRETATION FCF shall deliver all negotiated data in hard copied format within 60 days following the completion of on-orbit operations, and FCF shall have one preferred medium and data format for delivery of hard copies.	FCF A-Spec
ENGINEERING RESPONSE COMPLY All data will be provided to the PI on a hard-copied data (e.g. CD-ROM). The hard-copied data format will be specified in the Integration Agreement. The data will be provided within 60 days of completion of operations.	BSD

SRED REQUIREMENT	SRED Sec.
Req. DF1.1 - It is desired that FCF provide a Fluid Physics work volume that will accommodate 100% of the Fluid Physics Basis Experiments.	2.2.1
ENGINEERING INTERPRETATION Req. DF1.1 - It is desired that FCF provide a Fluid Physics work volume that will accommodate 100% of the Fluid Physics Basis Experiments.	FIR B-Spec Sec. 3.2.1.4
ENGINEERING RESPONSE COMPLY The Fluids Integrated Rack provides a science volume of approximately 490 liters (89 x 111 x 50 cm) for accommodating fluids physics experiments, or more than 40% of the available rack volume. The science volume mounting area will be 60 cm x 90 cm x 70 to 100 cm depending on the configuration of the hardware with respect to the connectors and UMLs. The actual usable volume available to the PI will be approximately 300 liters when access to optics bench mounted universal mounting locations (UMLs) and connectors for PI electrical power, data, etc. are considered. The science volume normally contains two facility-provided cameras and associated lenses, mirrors, and support electronics, and can accommodate experiment packages up to double middeck locker size (55 x 45 x 28 cm or 70 liters) with full facility providing imaging and illumination capabilities, and as large as 89x 111x 50 cm (490Liters), when facility provided imaging and illumination capabilities are not required. Unused science volume may be available for spare test cells or other PI-specific equipment. This volume is expected to be sufficient to accommodate the full set of basis experiments, with the caveat that some reduction in science is expected for experiment f3, due to an inability to accommodate the requested length of the test cell. Conceptual layouts of all 16 Basis Experiments on the FIR optics bench have been used to show compliance with this requirement and are provided in Appendix B to this document. * The volume available for science will be augmented with the addition of the SAR, by approximately two double middeck lockers. SAR will provide additional stowage for PI test cells and other hardware, as well as a capability to perform limited stand alone fluids experiments.	BSD Sec. B.2.3.3.1, B.2.3.3.2, B.3.1

SRED REQUIREMENT Req. DF1.2 - It is desired that the facility be able to concurrently accommodate at least 2 experiments within the work volume, each having its own diagnostic system.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. DF1.2 - It is desired that the facility be able to concurrently accommodate at least 2 experiments within the work volume, each having its own diagnostic system.	FIR B-Spec Sec. 3.2.1.16.1, 3.2.1.5
ENGINEERING RESPONSE COMPLY This science volume can accommodate multiple experiments simultaneously, with careful selection and design of the experiment packages, when the experiments are designed within the available resources (i.e., volume, power, crewtime, data acquisition, etc.). Multiple optical paths may be accommodated with the addition of PI-provided mirrors, etc. * FCF capability to accommodate two experiments is enhanced due to the ability of the SAR to accommodate stand-alone fluids science experiments. The FIR ability to accommodate additional experiments in its science volume is also enhanced with the addition of SAR due to additional resources of test cell stowage, video processing, and downlink capabilities, which SAR provides.	BSD

SRED REQUIREMENT Req. DF1.3 - It is desired that FCF provide multiple options for mounting PI hardware within the work volume and provide procedures that allow the positions of critical PI hardware elements to be established.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. DF1.3 - It is desired that FCF provide multiple options for mounting PI hardware within the work volume and provide procedures that allow the positions of critical PI hardware elements to be established.	FIR B-Spec Sec. 3.2.1.19, 3.2.1.4
ENGINEERING RESPONSE COMPLY The optics bench approach will use a "T"-type rail design that is machined on 100 mm centers in the bench. Spring-loaded ball bearing latches will allow the equipment to slide in the "T" grooves for positioning and then lock into place with a cam-type lever. Détentes located every 25 mm along the grooves provide accurate placement of equipment to within 2 mm or better when the ball bearings are located in the détentes. Additional precision, where required, can be accomplished using techniques such as direct referencing of position-critical equipment and test cells to the same mechanical interface and through the use of micro-positioning motors. Map-type index marks and colored grid lines along the détentes allow for rapid placement of components. This approach will ensure reliable and repeatable locations for mounted equipment. Standard M-6 mounting holes located every 100 mm provide alternative mounting locations. * FCF capability to meet this requirement is not affected by the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF1.4 - It is desired that FCF provide at least one level of containment for laser light (or other bright lights) that might pose a crew health hazard during experiment operation. Additional levels of containment, if required, may be provided by PI hardware.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. DF1.4 - It is desired that FCF provide at least one level of containment for laser light (or other bright lights) that might pose a crew health hazard during experiment operation. Additional levels of containment, if required, may be provided by PI hardware.	FIR B-Spec Sec. 3.2.2.11
ENGINEERING RESPONSE COMPLY FIR provides containment for lasers and bright lights through the use of a rack design, which is mostly sealed, coupled with the use of non-reflective coatings and surfaces. A rack door interlock will be provided to ensure that the facility lasers are powered off whenever the rack doors are opened. * FCF capability to meet this requirement is not affected by the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF1.5 - It is desired that FCF provide a temporary level of containment for fluids originating from PI hardware during experiment set up, reconfiguration, and test cell change-out.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. DF1.5 - It is desired that FCF provide a temporary level of containment for fluids originating from PI hardware during experiment set up, reconfiguration, and test cell change-out.	FIR B-Spec
ENGINEERING RESPONSE DO NOT COMPLY The PI will be required to provide a method of temporary containment for fluids during experiment set up, reconfiguration, and test cell changeout. This temporary level of containment would typically interface directly with the Experiment Package (EP) and would include the necessary capability to seal against fluid leaks around the hardware packages, to introduce or remove test cells or other equipment, to facilitate recovery from spills. The FIR will provide a means to install a glovebox and viewports in the rack doors in lieu of door panels to facilitate access to PI hardware. * FCF capability to meet this requirement is not affected by the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF1.6 - It is desired that FCF be capable of providing at least one level of containment for particulates larger than 1.0 mm originating from PI hardware during experiment operation.	SRED Sec. 1.2.2
ENGINEERING INTERPRETATION Req. DF1.6 - It is desired that FCF be capable of providing at least one level of containment for particulates larger than 1.0 mm originating from PI hardware during experiment operation.	FIR B-Spec
ENGINEERING RESPONSE DO NOT COMPLY Containment for particulate matter originating from the PI hardware is provided through the use of a PI-provided Experiment Package (EP). Some level of containment is provided by the rack itself during experiment operations, but since the rack is not entirely sealed, it cannot be used as a level of containment for particles or fluids, nor can it be easily modified to do so. The rack air filter will provide filtration of particles larger than 300 microns. * FCF capability to meet this requirement is not affected by the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF1.7 - It is desired that FCF provide capabilities for gas sampling and atmosphere circulation within the work volume that are similar to and compatible with analysis and filtration systems in the Combustion Element of FCF.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. DF1.7 - It is desired that FCF provide capabilities for gas sampling and atmosphere circulation within the work volume that are similar to and compatible with analysis and filtration systems in the Combustion Element of FCF.	FIR B-Spec
ENGINEERING RESPONSE COMPLY FIR will provide a capability to perform gas sampling using vacuum sample bottles for any sealed containers equipped with an appropriate interface port. These gas samples will be manually transported to the CIR GC for analysis. The FIR science volume is not a sealed volume, however, and FIR does not currently plan to be able to perform gas sampling of this volume. Atmosphere circulation in the science volume is required by ISS whenever the rack is powered in order to perform smoke detection and heat rejection. * FCF capability to meet this requirement is not affected by the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF4.1 - It is desired that the facility measure the relative humidity, accurate to within +/- 10%, in the science volume.	SRED Sec. 2.2.1
ENGINEERING INTERPRETATION Req. DF4.1 - It is desired that the facility measure the relative humidity, accurate to within +/- 10%, in the science volume.	FIR B-Spec
ENGINEERING RESPONSE COMPLY The FIR will include an atmosphere monitoring assembly, which will measure temperature, pressure, and humidity in the science volume. Accuracy of the unit will meet the stated requirement. FIR will also provide a capability to interface with a humidity or other sensors located in the PI-provided Experiment Package (EP). * FCF capability to meet this requirement is not affected by the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF7.1 - It is desired that FCF provide the ability to implement a “sleep” mode on PI-provided circuit cards (particularly those PI-provided cards used in facility computers) to selectively conserve power resources during low levels of use.	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. DF7.1 - It is desired that FCF provide the ability to implement a “sleep” mode on PI-provided circuit cards (particularly those PI-provided cards used in facility computers) to selectively conserve power resources during low levels of use.	FIR B-Spec
ENGINEERING RESPONSE COMPLY The facility will make provisions for interfacing with PI-provided electronic cards to permit "sleep mode” operations to occur during low-use periods. The PI will have to provide the method on board to turn off the power. FIR will provide the method to control this circuitry. * FCF capability to meet this requirement is not affected by the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF8.1 - It is highly desirable that the standard deviation from mean intensity of the uniform background lighting be less than 0.2 percent (9 bit).	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. DF8.1 - It is highly desirable that the standard deviation from mean intensity of the uniform background lighting be less than 0.2 percent (9 bit).	FIR B-Spec
ENGINEERING RESPONSE DO NOT COMPLY FIR cannot meet the requirement to provide background lighting, which is uniform to within 0.2 percent. The FIR will provide backlight with a uniformity of better than 10% fiberweave backlights. Uniformities on the order of 0.2 percent are not considered to be achievable. Non-uniformities in the 10% range can be post-processed out of the imagery, when necessary. In order to provide more uniform lighting than is currently being provided, a light source of very low intensity or which introduces large amounts of heat into the science volume near the test cell would be required. * FCF capabilities with regard to illumination do not change with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF8.2 - It is desired that the illumination not limit the optical resolution and not cause ringing in the image (i.e., the light should be, at most, partially coherent).	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. DF8.2 - It is desired that the illumination not limit the optical resolution and not cause ringing in the image (i.e., the light should be, at most, partially coherent).	FIR B-Spec
ENGINEERING RESPONSE COMPLY The FIR will provide a polychromatic back light delivered via fiber bundle designed to provide light for the standard 10 x 10cm test cell of up to 1 mW/cm2, sufficient to provide good imagery, and will not cause ringing in the image * FCF capabilities with regard to illumination do not change with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF9.1 - It is desired that FCF be capable of maintaining at least 4 lasers on orbit and have additional laser heads available for modifications and change-out. It is presumed that solid state lasers will be used whenever possible.	SRED Sec. 2.2.2
ENGINEERING INTERPRETATION Req. DF9.1 - It is desired that FCF be capable of maintaining at least 4 lasers on orbit and have additional laser heads available for modifications and change-out. It is presumed that solid-state lasers will be used whenever possible.	FIR B-Spec
ENGINEERING RESPONSE DO NOT COMPLY The FIR will provide three facility lasers as the standard on-orbit complement. The lasers provided in the initial FIR configuration will include: 1) One Nd:YAG laser whose (CW) output is at least 50 mW at the test cell (high power, good beam quality) 2) Two high-powered diode lasers (10 mW at 680 nm).	BSD

SRED REQUIREMENT Req. DF14.1 - It is desirable to have at least two viewing directions be accessible with zoom capability.	SRED Sec. 2.3.2
ENGINEERING INTERPRETATION Req. DF14.1 - It is desirable to have at least two viewing directions be accessible with zoom capability.	FIR B-Spec Sec. 3.2.1.17, 3.2.1.21
ENGINEERING RESPONSE COMPLY FIR will provide three cameras with a standard zoom capability, additional zoom lens can be accommodated as PI provide hardware.	BSD

SRED REQUIREMENT Req. DF14.2 - It is desirable to have images of directly opposite views; e.g., front and rear view of an object should be accessible.	SRED Sec. 2.3.2
ENGINEERING INTERPRETATION Req. DF14.2 - It is desirable to have images of directly opposite views; e.g., front and rear view of an object should be accessible.	FIR B-Spec
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR provides the capability to image directly opposite views of the test cell, when the PI hardware is used to provide optical path manipulation, e.g., mirrors. * FCF capabilities with regard to this requirement do not change with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF14.3 - It is desirable to have ability to image two orthogonal views side by side with the same camera.	SRED Sec. 2.3.2
ENGINEERING INTERPRETATION Req. DF14.3 - It is desirable to have ability to image two orthogonal views side by side with the same camera.	FIR B-Spec
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR can provide the capability to image two orthogonal views side by side with the same camera, with the addition of PI hardware, such as switching mirrors. * FCF capabilities with regard to this requirement do not change with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF18.1 - It is desired that the facility not preclude higher camera frame-rates (e.g., 2000 fps).	SRED Sec. 2.3.3
ENGINEERING INTERPRETATION Req. DF18.1 - It is desired that the facility not preclude higher camera frame-rates (e.g., 2000 fps).	FIR B-Spec Sec. 3.2.1.24
ENGINEERING RESPONSE WILL COMPLY FCF incorporates high speed imaging capability following the launch of the SAR rack. Prior to SAR launch, FIR supports three camera systems, which currently include two high-resolution cameras and one color camera. With the launch of SAR, all planned capabilities, i.e., high-resolution, color, and high frame-rate imaging will become standard facility capabilities. * SAR launch will permit additional resources to be directed toward a data acquisition and control of a high speed imaging system, as well as imaging data processing and storage.	BSD

SRED REQUIREMENT Req. DF19.1 - Continuous communication between the experiment ground operations team and the facility is highly desirable.	SRED Sec. 2.3.3
ENGINEERING INTERPRETATION Req. DF19.1 - Continuous communication between the PI team and the facility is highly desirable.	FIR B-Spec
ENGINEERING RESPONSE DO NOT COMPLY FIR will not be the constraining factor limiting PI communication with the facility. Communication with ISS is predicted to be available for approximately 40 to 60% of every 90 minute orbit. Continuous communication via the relay satellite will not be possible due to obscuration by the earth, the ISS itself, and for other reasons. * FCF capabilities with regard to this requirement do not change with the addition of the SAR.	BSD

SRED REQUIREMENT	SRED Sec.
Req. DF20 - It is desired that FCF provide the following optical diagnostic capabilities as FCF supplied hardware and software per the recommendations in table DF20: DF20.1 General Video Imaging; DF20.2 Video Microscopy; DF20.3 Static Light Scattering; DF20.4 Dynamic Light Scattering; DF20.5 Shadowgraphy; DF20.5 Particle Image Velocimetry; DF20.6 Shearing Interferometry; DF20.7 Surface Profilometry.	2.3.3
ENGINEERING INTERPRETATION	FIR B-Spec Sec.
It is desired that FCF provide the following optical diagnostic capabilities as FCF supplied hardware and software per the recommendations in table DF20: DF20.1 General Video Imaging; DF20.2 Video Microscopy; DF20.3 Static Light Scattering; DF20.4 Dynamic Light Scattering; DF20.5 Shadowgraphy; DF20.5 Particle Image Velocimetry; DF20.6 Shearing Interferometry; DF20.7 Surface Profilometry.	3.2.1.26
ENGINEERING RESPONSE	BSD Sec.
COMPLY WITH PI HARDWARE	

FIR CAPABILITY

DIAGNOSTIC TECHNIQUE	BASIS EXPERIMENT	RECOMMENDED BASELINE CAPABILITY	**RECOMMENDED UPDATED CAPABILITY**	**FIR Provided Capability**	**Comments**
General imaging	f1 to f16	multiple views, zoom capability, particle tracking, color and b&w, frame rates to 300 per sec	high frame rates (to 2000 per sec)	Y	FIR Cameras can be used as general imaging cameras with FIR provided lenses or PI provided lenses
IR imaging	f1, f11		as required	N	FIR will not preclude the use of a PI provided IR Camera and lens
Video microscopy	f1, f2, f10, f15,f16	2 views		Y	If magnifications greater than optem lens can provide are required, PI must supply appropriate lens
Static and dynamic light scattering	f4, f5, f7, f12, f16	required			

Shadowgraph	f11	required		Y	FIR provides a light source capable of producing shadowgraphs but PI must provide pin hole and imaging screen
Schlieren			as required	N	The light sources and imagers that are provided by FIR could be used in a Schlieren system but FIR does not provide the optics for this type of imaging system. At this time there is no Basis Experiment requiring this imaging technique.
Color schlieren			as required	N	The light sources and imagers that are provided by FIR could be used in a Color Schlieren system but FIR does not provide the focusing optics for this type of imaging system. At this time there is no Basis Experiment requiring this imaging technique.
Particle image velocimetry	f1, f2, f3, f10, f11	required		N*	The light sources and imagers that are provided by FIR could be used for PIV but FIR does not provide the light sheet optics for this technique. Additionally it is felt that the light sheet optics for each of the experiments listed is to specific that it would require a unique light sheet generator for every experiment.

Laser induced fluorescence	f10		as required	Y	This is a technique that can be performed using the FIR provided lasers, provided the PI provided the sample containing particles that could absorb and radiate the energy from the FIR lasers.
Mach-Zehnder interferometry	f8, f9, f12		as required	N* **	FIR does not provide the two beam splitters required for this interferometric technique. However FIR does provide an illumination source and mirrors that could be configured into this type of interferometer.
Michelson interferometry	f1, f12		as required	N* **	FIR does not provide the beam splitter and compensating plate required for this interferometric technique. However FIR does provide an illumination source and imager that could be configured into this type of interferometric configuration.
Twyman-Green interferometry	f12		as required	N* **	FIR does not provide the beam splitter required for this interferometric technique. However FIR does provide an illumination source, collimator, mirror, and imager that could be configured into this type of interferometric configuration.
Point diffraction interferometry	f8, f9		as required	N* **	This interferometric technique is similar to the Twyman-Green interferometer above.

Shearing interferometry	f1, f8 f9, f12, f14	required		N* **	FIR does not provide the shear plate required for this interferometric technique. However FIR does provide an illumination source and imager that could be configured into this type of interferometric configuration.
Liquid crystal point diffraction interferometry	f8, f9		as required	N* **	
Laser feedback interferometry	f1		as required	N* **	The lasers provided by FIR are not configured to accommodate this type of interferometric technique.
Surface profilometry	f11	required		N*	FIR can supply a laser for use in a interferometer configuration to measure surface shapes or roughness.
Ronchi (surface slopes measurement)	f11		as required	N	FIR does not supply a Ronchi grating
Laser Induced Photochemical Anemometry			as required	N	Not required by any basis experiments
Confocal and fluorescence microscopy	f16		as required	N**	Experiment specific
Laser tweezers	f16		as required	N	Experiment specific
Spectrophotometry	f16		as required	N	Experiment specific
Spectroscopy; DTS DWS	f15		as required	N	Experiment specific

* This hardware requires integration into the PI test cell for optimum efficiency.

** Setup and configuration of these items would require real time positional alignment with real time feedback to the investigator.

*** FCF capability to meet these diagnostics requirements is predicted to be enhanced with the addition of the SAR, due to additional stowage as well as image processing and storage capability.	

<table>
<tr><td>SRED REQUIREMENT

Req. DF25.1 - FCF should provide an analog to digital conversion system available for use by PI hardware and having as many as possible of the following characteristics:

• Adjustable gain.
• Selectable sampling at up to 20 kHz rates with sample and hold capability.
• Monopolar or bipolar selection per channel, in order to take full advantage of the A/D dynamic range (e.g., ±1, ±2, ±5, ±10 Volts, similar for Ohms and Amps).
• Single-ended and differential-ended types of measurement used simultaneously.
• Equivalent resolution of 8 1/2 digits.
• Upgradeable to 256 analog channels for future use.
• Easily interface with existing laboratory and commercial instrumentation.</td><td>SRED Sec.

2.4.1</td></tr>
<tr><td>ENGINEERING INTERPRETATION

FCF should provide an analog to digital conversion system available for use by PI hardware and having as many as possible of the following characteristics:

• Adjustable gain.
• Selectable sampling at up to 20 kHz rates with sample and hold capability.
• Monopolar or bipolar selection per channel, in order to take full advantage of the A/D dynamic range (e.g., ±1, ±2, ±5, ±10 Volts, similar for Ohms and Amps).
• Single-ended and differential-ended types of measurement used simultaneously.
• Equivalent resolution of 8 1/2 digits.
• Upgradeable to 256 analog channels for future use.
Easily interface with existing laboratory and commercial instrumentation.</td><td>FIR B-Spec Sec.

3.2.1.42</td></tr>
<tr><td>ENGINEERING RESPONSE

COMPLY

FIR has allocated 1 card slot for acquisition of experiment-specific analog data in the FSAP. FIR will provide 20 differential analog input lines for analog to digital conversion of PI data.

* FCF capabilities with regards to this desirement are not changed with the addition of the SAR.</td><td>BSD</td></tr>
</table>

SRED REQUIREMENT Req. DF27.1 - It is desired that all data should be recorded using standard commercial formats that can be easily accessed by PI software.	SRED Sec. 2.4.2
ENGINEERING INTERPRETATION It is desired that all data should be recorded using standard commercial formats that can be easily accessed by PI software.	FIR B-Spec Sec. 3.2.1.47.1
ENGINEERING RESPONSE COMPLY FIR software will be developed to best suit the needs of the PI and the capabilities of the platform. Commercial formats may be used if well suited. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF27.2 - FCF should provide a minimum of 32 Mbytes of CPU bus speed storage (e.g., RAM) for experiment-specific non-image data (e.g., transducer readings).	SRED Sec. 2.4.2
ENGINEERING INTERPRETATION Req. DF27.2 - FCF should provide a minimum of 32 Mbytes of CPU bus speed storage (e.g., RAM) for experiment-specific non-image data (e.g., transducer readings).	FIR B-Spec Sec. 3.2.1.47.3
ENGINEERING RESPONSE COMPLY FIR will provide 32 MB of RAM for experiment-specific non-image data. Compliance will be shown through the FIR parts list where 128 MB RAM board will be listed. FIR will only use 64 MB, leaving at least 32 MB for the experiment. * FCF capabilities with regards to this capability are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF28.1 - It is desired that FCF provide capability to tag data at selectable precision and frequency. The precision/resolution on time tagging should be consistent with the data sampling rate used.	SRED Sec. 2.4.2
ENGINEERING INTERPRETATION Req. DF28.1 - It is desired that FCF provide capability to tag data at selectable precision and frequency. The precision/resolution on time tagging should be consistent with the data sampling rate used.	FIR B-Spec
ENGINEERING RESPONSE COMPLY The FIR will time stamp acquired digital and video data using the FSAP clock with an accuracy of ±1 millisecond. All data frames, digital or video, collected at 1000 Hz or less, will be individually time tagged. Data taken at rates higher than 1000 Hz will be tagged at 10 millisecond intervals. For those data frames that are not tagged, the time collection will be determined by interpolation. Due to the very low overhead associated with adding time tags to experiment data streams, data tagging will occur at the highest frequency permitted by the system. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF29.1 - It is desired that provisions be provided to increase the number of available D/A channels to 64 as demand increases.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF29.1 - It is desired that provisions be provided to increase the number of available D/A channels to 64 as demand increases.	FIR B-Spec
ENGINEERING RESPONSE COMPLY FIR provides 8 analog output channels, with the capability to increase the number of channels to 64. PI-specific cards can be used to augment this capability. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF29.2 - It is desired that a variety of wave forms be generated at selectable frequencies to 1 MHz and selectable amplitudes.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF29.2 - It is desired that a variety of wave forms be generated at selectable frequencies to 1 MHz and selectable amplitudes..	FIR B-Spec
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE At least two empty card slots will be provided for the PI in the FSAP, which may be utilized to meet the above desirement. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF32 - It is recommended that an FCF Fluid Physics computer accommodate any or all of the following experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume. The recommended single board capabilities include: DF32.1 State-of-the-art frame grabber; DF32.2 Oscilloscope board; DF32.3 Lock-in amplifier; DF32.4 Time correlator (which support both digital and analog inputs); DF32.5 Strain-gauge measurement; DF32.6 Thermocouple reference and amplifier; DF32.7 Frequency synthesizer.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF32 - It is recommended that an FCF Fluid Physics computer accommodate any or all of the following experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume. The recommended single board capabilities include: DF32.1 State-of-the-art frame grabber; DF32.2 Oscilloscope board; DF32.3 Lock-in amplifier; DF32.4 Time correlator (which support both digital and analog inputs); DF32.5 Strain-gauge measurement; DF32.6 Thermocouple reference and amplifier; DF32.7 Frequency synthesizer.	FIR B-Spec Sec. 3.2.1.42
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR meets the above desirement by providing two empty card slots in the FSAP, which may be utilized by the PI to meet the above desirement. The facility will provide a list of compatible cards, which may be used in the FSAP, if desired. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF32.1 - It is recommended that an FCF Fluid Physics computer accommodate State-of-the-art frame grabber experiment-specific plug-in boards (up to 10 slots) and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF32.1 - It is recommended that an FCF Fluid Physics computer accommodate State-of-the-art frame grabber experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	FIR B-Spec Sec. 3.2.1.42
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR meets the above desirement by providing two empty card slots in the FSAP, which may be utilized by the PI to meet the above desirement. The facility will provide interface specifications as necessary. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF32.2 - It is recommended that an FCF Fluid Physics computer accommodate Oscilloscope board experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF32.2 - It is recommended that an FCF Fluid Physics computer accommodate Oscilloscope board experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	FIR B-Spec Sec. 3.2.1.42
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR meets the above desirement by providing two empty card slots in the FSAP, which may be utilized by the PI to meet the above desirement. The facility will provide interface specifications as necessary. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF32.3 - It is recommended that an FCF Fluid Physics computer accommodate Lock-in amplifier experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF32.3 - It is recommended that an FCF Fluid Physics computer accommodate Lock-in amplifier experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	FIR B-Spec Sec. 3.2.1.42
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR meets the above desirement by providing two empty card slots in the FSAP, which may be utilized by the PI to meet the above desirement. The facility will provide interface specifications as necessary. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF32.4 - It is recommended that an FCF Fluid Physics computer accommodate Time correlator (which support both digital and analog inputs) experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF32.4 - It is recommended that an FCF Fluid Physics computer accommodate Time correlator (which support both digital and analog inputs) experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume	FIR B-Spec Sec. 3.2.1.42
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR meets the above desirement by providing two empty card slots in the FSAP, which may be utilized by the PI to meet the above desirement. The facility will provide interface specifications as necessary. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF32.5 - It is recommended that an FCF Fluid Physics computer accommodate Strain-gauge measurement experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. Df32.5 - It is recommended that an FCF Fluid Physics computer accommodate Strain-gauge measurement experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	FIR B-Spec Sec. 3.2.1.42
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR meets the above desirement by providing two empty card slots in the FSAP, which may be utilized by the PI to meet the above desirement. The facility will provide interface specifications as necessary. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF32.6 - It is recommended that an FCF Fluid Physics computer accommodate Thermocouple reference and amplifier experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF32.6 - It is recommended that an FCF Fluid Physics computer accommodate Thermocouple reference and amplifier experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	FIR B-Spec Sec. 3.2.1.42
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR meets the above desirement by providing two empty card slots in the FSAP, which may be utilized by the PI to meet the above desirement. The facility will provide interface specifications as necessary. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF32.7 - It is recommended that an FCF Fluid Physics computer accommodate Frequency synthesizer experiment-specific plug-in boards and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF32.7 - It is recommended that an FCF Fluid Physics computer accommodate Frequency synthesizer experiment-specific plug-in boards (up to 10 slots) and associated PI software. The computer should be located near the dedicated Fluid Physics volume.	FIR B-Spec Sec. 3.2.1.42
ENGINEERING RESPONSE COMPLY WITH PI HARDWARE FIR meets the above desirement by providing two empty card slots in the FSAP, which may be utilized by the PI to meet the above desirement. The facility will provide interface specifications as necessary. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DF32.8 - It is desired that FCF provide a custom electronics enclosure to provide accommodations for high-quality, low-noise measurement capabilities that may require careful protection from electromagnetic interference and temperature variations.	SRED Sec. 2.4.3
ENGINEERING INTERPRETATION Req. DF32.8 - It is desired that FCF provide a custom electronics enclosure to provide accommodations for high-quality, low-noise measurement capabilities that may require careful protection from electromagnetic interference and temperature variations.	FIR B-Spec
ENGINEERING RESPONSE COMPLY Low-noise measurement capabilities will be provided by an analog card in the FSAP. The FSAP will be designed to shield against EMI. FIR can accept signals from any type of transducer by modifying the transducer output to be compatible with FIR. * FCF capabilities with regards to this desirement are not changed with the addition of the SAR.	BSD

SRED REQUIREMENT Req. DC1 - It is desirable to have a quasi-steady acceleration level of $10^{-4}g_0$ during conduct of the experiments.	SRED Sec. 3.2.1
ENGINEERING INTERPRETATION It is desirable to have a quasi-steady acceleration level of $10^{-4}g_0$ during conduct of the experiments.	CIR B-Spec Sec. 3.2.1.11
ENGINEERING RESPONSE COMPLY /FCF COMPLY The Active Rack Isolation System (ARIS) will be installed in the CIR. ARIS will keep the rack internal environment well below this requirement when subjected to the projected ISS environment.	BSD Sec. 5.1.3

SRED REQUIREMENT Req. DC5.1 - It is desirable to have the ability to burn in a 100% oxygen environment. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	SRED Sec. 3.2.2
ENGINEERING INTERPRETATION It is desirable to have the ability to burn in a 100% oxygen environment. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	CIR B-Spec Sec. 3.2.1.16, 3.3.6.30.3
ENGINEERING RESPONSE MAY NOT COMPLY /FCF MAY NOT COMPLY Safety concerns have driven the FCF design to a maximum of 85% oxygen concentration.	BSD Sec. A.2.2.4.2.1

SRED REQUIREMENT Req. DC5.2 - It is desirable to have the ability to supply gas from more than one premixed bottle during a single run. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	SRED Sec. 3.2.2
ENGINEERING INTERPRETATION It is desirable to have the ability to supply gas from more than one premixed bottle during a single run.	CIR B-Spec Sec. 3.2.1.18, 3.3.6.30
ENGINEERING RESPONSE COMPLY/FCF COMPLY FCF supports the supply of gas from up to two premixed bottles. Bottles sizes must not exceed 3.8 L and 2.25L.	BSD Sec. A2.2.4.2.1

SRED REQUIREMENT Req. DC6.1 - It is extremely desirable to have the capability to flow premixed fuel and oxidizer through the test section in a controlled manner. Such experiments cannot utilize a re-circulating flow. Overall (fuel and oxidizer) flow rates may range to 4,000 scc/sec. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	SRED Sec. 3.2.3
ENGINEERING INTERPRETATION It is extremely desirable to have the capability to flow premixed fuel and oxidizer through the test section in a controlled manner. Such experiments cannot utilize a re-circulating flow. Overall (fuel and oxidizer) flow rates may range to 4,000 scc/sec.	CIR B-Spec Sec. 3.2.1.19, 3.2.1.20
ENGINEERING RESPONSE PARTLY COMPLY /FCF PARTLY COMPLY The FCF can provide flow-through capability dependent on oxygen concentration. Durations will be a function of both oxygen concentration and flow rate desired. The maximum flow rate will be 90 SLM (1500 cc/sec) for oxygen concentrations up to 30%. The ISS VES will not allow oxygen concentrations greater than 30%. Experiments requiring flow rates greater than 1500 cc/sec, will need to re-circulate the chamber environment via fans provided on the experiment package.	BSD Sec. A.2.3.4.2

SRED REQUIREMENT Req. DC8.1 - It is desirable to accommodate framing rates to 1,000/sec. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	SRED Sec. 3.3.1
ENGINEERING INTERPRETATION It is desirable to accommodate framing rates to 1,000/sec.	CIR B-Spec Sec. 3.2.1.23, 3.2.1.40.2
ENGINEERING RESPONSE MAY NOT COMPLY/FCF WILL COMPLY WITH PI HARDWARE The maximum frame-rate provided by the FCF is 110 fps. PI-provided packages with higher frame-rates could be supported as long as those packages are compatible with FCF image acquisition systems. Those systems have a maximum acquisition rate of 30 MB/sec and have a hard drive capacity of 36 GB. Improved image acquisition capabilities may be added in the SAR.	BSD Sec. A.2.2.5, 5.2.5, A.2.2.5.2

SRED REQUIREMENT Req. DC9.1 - It is desirable to accommodate framing rates to 1,000/sec for IR imaging. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	SRED Sec. 3.3.1
ENGINEERING INTERPRETATION It is desirable to accommodate framing rates to 1,000/sec for IR imaging. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	CIR B-Spec Sec. 3.2.1.23.5, 3.2.1.40.2
ENGINEERING RESPONSE MAY NOT COMPLY/FCF WILL COMPLY WITH PI HARDWARE The maximum frame-rate provided by the FCF IR imaging diagnostic package is 60 fps. PI-provided packages with higher frame-rates could be supported as long as those packages are compatible with FCF image acquisition systems. Those systems have a maximum acquisition rate of 30 MB/sec and have a hard drive capacity of 36 GB. Improved image acquisition capabilities may be added in the SAR.	BSD Sec. A.2.2.5.4, A.2.2.5.5, 5.2.5

SRED REQUIREMENT Req. DC10.1 - It is desirable to accommodate framing rates to 1,000/sec for UV imaging. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	SRED Sec. 3.3.1
ENGINEERING INTERPRETATION It is desirable to accommodate framing rates to 1,000/sec for UV imaging. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	CIR B-Spec Sec. 3.2.1.23.6, 3.2.1.40.2
ENGINEERING RESPONSE MAY NOT COMPLY/FCF WILL COMPLY WITH PI HARDWARE The maximum frame-rate provided by the FCF UV imaging diagnostic package is 60 fps. PI-provided packages with higher frame-rates could be supported as long as those packages are compatible with FCF image acquisition systems. Those systems have a maximum acquisition rate of 30 MB/sec and have a hard drive capacity of 36 GB. Improved image acquisition capabilities may be added in the SAR.	BSD Sec. A.2.2.5.4, 5.2.5

SRED REQUIREMENT Req. DC12.1 - It is desirable to accommodate sampling rates to 1,000 samples/second for temperature field measurements. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	SRED Sec. 3.3.2
ENGINEERING INTERPRETATION It is desirable to accommodate sampling rates to 1,000 samples/second for temperature field measurements. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	CIR B-Spec Sec. 3.2.1.24, 3.2.1.25, 3.2.1.40.2
ENGINEERING RESPONSE MAY NOT COMPLY/FCF WILL COMPLY WITH PI HARDWARE The maximum frame-rate provided by an FCF imaging package is 110 fps. PI-provided packages with higher frame-rates could be supported as long as those packages are compatible with FCF image acquisition systems. Those systems have a maximum acquisition rate of 30 MB/sec and have a hard drive capacity of 36 GB. Improved image acquisition capabilities may be added in the SAR.	BSD Sec. A2.2.5, 5.2.5, A.2.2.5.2

SRED REQUIREMENT Req. DC17.1 - It is desirable to accommodate imaging rates to l,000/second for image based velocity measurement systems. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	SRED Sec. 3.3.3
ENGINEERING INTERPRETATION It is desirable to accommodate imaging rates to l,000/second for image-based velocity measurement systems. Compliance shall be demonstrated by analysis and conceptual layouts that show that the FCF, augmented by PI-specific hardware, could provide the desired capability.	CIR B-Spec Sec. 3.2.1.32, 3.2.1.33, 3.2.1.40.2
ENGINEERING RESPONSE MAY NOT COMPLY/FCF WILL COMPLY WITH PI HARDWARE The maximum frame-rate provided by an FCF imaging package is 110 fps. PI-provided packages with higher frame-rates could be supported as long as those packages are compatible with FCF image acquisition systems. Those systems have a maximum acquisition rate of 30 MB/sec and have a hard drive capacity of 36 GB. Improved image acquisition capabilities may be added in the SAR.	BSD Sec. A.2.2.5, 5.2.5, A.2.2.5.2

SRED REQUIREMENT Req. DO1 - It is desirable that FCF shall provide video monitoring (standard video quality) of the Astronaut crew to the PI team during PI hardware installation and servicing to enable real-time support by ground personnel and to provide a record of the on-orbit crew operations.	SRED Sec. 4.3
ENGINEERING INTERPRETATION It is desirable that FCF provide video monitoring (standard video quality) of the Astronaut crew to the PI team during PI hardware installation and servicing to enable real-time support by ground personnel and to provide a record of the on-orbit crew operations.	FCF A-Spec
ENGINEERING RESPONSE WILL COMPLY This is the preferred mode of operation of the FCF. Whenever practical, the FCF operations will specify video be required during hardware installation, as well as requiring closeout photos after installation has been completed.	BSD

SRED REQUIREMENT Req. DO2 - It is desirable that FCF shall provide a video monitor for the Astronaut crew that displays instructions, images, or other supporting data from ground personnel for the purpose of enhancing the efficiency of PI hardware setup, servicing, and operations interactions.	SRED Sec. 4.3
ENGINEERING INTERPRETATION It is desirable that FCF provide a video monitor for the Astronaut crew that displays instructions, images, or other supporting data from ground personnel for the purpose of enhancing the efficiency of PI hardware setup, servicing, and operations interactions.	FCF A-Spec Sec. 3.7.3.3.3 D
ENGINEERING RESPONSE COMPLY The FCF current plan is to use the Station Support Computer (SSC) to provide this function. The SSC can accept video, images, instructions, etc. A monitor may become part of the SAR rack.	BSD

SRED REQUIREMENT Req. DO3 - It is desired that, during mission operations, FCF PIs will, typically, be located at their home institution and receive data from their experiment at their home institution. FCF shall provide the equipment, software, and operational procedures to permit this. Provisions should be made to distribute all relevant data from a given experiment (including near-real-time science, environment, FCF status, and etceteras as negotiated) to at least 10 PI data terminals spread among at least 3 different PI sites that may be located anywhere.	SRED Sec. 4.3
ENGINEERING INTERPRETATION It is desired that, during mission operations, FCF PIs will typical be located at their home institution and receive data from their experiment at their home institution. FCF shall provide the equipment, software, and operational procedures to permit this. Provisions should be made to distribute all relevant data from a given experiment (including near-real-time science, environment, FCF status, as negotiated) to at least 10 PI terminals spread among at least 3 different PI sites that may be located any where.	FCF A-Spec Sec. 3.1.1.4, 3.1.5.1.6
ENGINEERING RESPONSE MAY NOT COMPLY The ISS Ground System and GRC Telescience Support Center will be able to support distribution of all relevant data to the PI site, but it is likely that other factors such as budget and schedule will limit the total number of terminals and the number of different sites receiving data.	BSD

Appendix A – CIR Basis Experiments Compliance

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Science Requirements Document Summary for

Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF) (c1)

SRD Date: April 20, 1995

Principal Investigator: Dr. M. Yousef Bahadori

Project Scientist: Dennis Stocker

Project Manager: Frank Vergilii

Experiment Objective:

The study is aimed at identifying the mechanisms involved in the interaction of observed large-scale structure that directly influence the flame characteristics of gas jet diffusion flames. This will further our understanding of the naturally occurring disturbances that are an inherent part of the transitional and turbulent flame, and are observed in microgravity ground-based facilities.

Experiment Summary:

A controlled, well-defined set of disturbances is imposed on a laminar flame by means of an iris at the base of the flame.

Requirement Type: *Experiment Operating Conditions*	SRD Requirements for c1: *Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)*	FCF Capability	Compliance Comments
Test Section Dimensions Volume Dimensions Shape	Minimum free volume of 48 L. Fuel nozzle centerline shall be a minimum of 15 cm away from the chamber side walls and placed as symmetrically as possible. Nozzle tip shall be a minimum of 10 cm from the bottom of the test chamber and 24 cm from the top of the chamber. Entire internal surface of the chamber and any internal structures, to the extent possible, shall have an absorptivity (emissivity) of at least 0.9 in the range of 0.3 to 9.0 microns. A metallic mesh of approximately 20 cm in diameter shall be located 3.0 +/- 0.5 cm below the chamber wall opposite the nozzle tip. Its emissivity should also be at least 0.9 in the range of 0.3 to 9.0 microns.	CIR chamber free volume is 100 L Fuel nozzle is part of PI H/W (CIA) Chamber internal surface finish not part of SRED Mesh PI-provided w/CIA	
Fuel State Physical state of fuel Storage Distribution Mixing Handling	A fuel injector (nozzle) is used to supply fuel to the test section. Inner diameter of the nozzle shall be constant for a minimum of 40 nozzle diameters upstream of the tip. Nozzle shall be stainless-steel and smooth inside and outside. Nozzle shall have an externally tapered tip (25 to 45 degrees taper angle) with 0.165 cm inner diameter and 0.2288 cm outer diameter, with tolerances less than +/- 5%, and known to +/- 1%. Nozzle must be perpendicular within +/- 1 degree to the iris plane. Fuel is propane with a minimum purity of 99.5%. Fuel is injected through the nozzle in the vapor state.	Fuel nozzle part of PI H/W (CIA) Fuel is PI-provided CIR offers 1 or 2.25L bottles	*SRED App. B states fuels to be methane and propane.*

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**
Ignition Igniter Power Control Geometry	Recommended that the flame be ignited by means of a hot-wire. Ignitor removal from the flame within 2 seconds after ignition, with a retraction time of the order of 0.5 sec.	Ignitor PI-provided in CIA	[5 sec used on flight].
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	10^{-4} g or less in the frequency range of 0 to 15 Hz.	CIR will operate with an active ARIS	
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	Initial pressure shall be 1 +/- 0.05 atm.	CIR complies	
Operating Temperature Gas temperature control Condensed phase fuel temperature control	Initial temperature shall be between 12 and 27 degrees C.	CIR complies If range is within cabin air temperature range	
Oxidizer Composition Components Range Accuracy	Dry mixture of 22% +/- 0.3% oxygen and 78% nitrogen by volume at the beginning of the experiment, and known to +/- 0.1% on a molar basis. The mixture of oxygen and nitrogen shall have a minimum purity of 99.5%	The O2/N2 delivered in combinations of any of the 3 standard oxidant bottles. 1L 85%O2, 2.25L 50% O2 or 3.8L 30% O2 all with balanced N2. ISS N2 will be used to Dilute the proper mixture	Oxygen specified in SRED App. B is 15%-30%

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**
Fuel Flow Flow rate Range Duration Accuracy Stability	Fuel flow is 3.65 mg/sec with a tolerance of +/- 0.1 mg/sec. Measurement accuracy shall be +/- 2% by mass.	CIR provides 3 to 33.3cc/s	*Flow Rate in SRED App. B and Figure C6 is 3-30 cc/s*
Oxidizer Flow Flow rate Range Duration Accuracy Stability	N/A		
Number, duration of tests	Four tests at varying frequencies from1 to 10 Hz. After the fuel is turned off, it is desirable to let the flame burn to extinction.	Bottle and venting combination can be determined for the desired number of tests. The max. duration for propane would be approx. 500 *sec.*	[Limited by GASCan Air. Would Want more]. *SRED App. B indicates 15-20 test points. Fig. C7 indicates 20-32 test points, duration 350-650s.*

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**
Other Experiment Conditions	Mechanism is required to impose a well-defined (known frequency and amplitude) near-sinusoidal disturbance on the flame. Amplitude must be controllable and be within +/- 2% of the values in the test matrix. Frequency must be controllable and be within +/- 1% of the values in the test matrix. Minimum closed diameter = 1.2 cm, maximum open diameter = 2.2 cm. Desired fully open position before and after disturbances is 4.0 cm dia. The phase of the iris shall be known to with +/- 5 degrees during pulsing. Plane of the iris shall be approximately 5 +/- 0.5 mm above the nozzle tip, with its center coincident with the nozzle axis. The offset shall not exceed 0.2 mm.	PI-provided H/W (CIA). CIR provides interface in the chamber IRR for CIA instrumentation control.	

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**

Requirement Type: *Experiment Measurements*	SRD Requirements for c1: *Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)*	FCF Capability	Compliance Comments
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	Two non-collinear, preferably orthogonal, flame views. Desired to have at least one color view. Field of view is 18 cm along the nozzle axis by a minimum of 8 cm wide centered at the nozzle, starting from about 2 cm below the nozzle tip. Minimum depth of field is 5 cm. Spatial resolution requirements are 0.5 to 1 mm, at 50% modulation over the field of view. Minimum framing rate of 30 frames/sec. One view optimized to visualize the passage of structures along the flame by adjusting the shutter speed and aperture based on the microgravity ground-based results. One color view optimized to visualize the dimmer parts of the flame such as the tip and the blue base. Length scale in both horizontal and vertical directions for both cameras.	1 color view provided. 30 fps. 6 to 35 cm. sq. FOV. 230µm to 1.4 mm resolution at 50% modulation depending on zoom position. (0.7mm resolution for 18cm. FOV). Depth of field depending on adjustable iris setting 2 lux sensitivity at full aperture. Shutter speed control is available. 1 B/W intensified view provided 30fps 4.2 to 21.2 cm. sq. FOV 83-413 µm resolution depending on zoom position. (0.35mm resolution for 18cm. FOV) Depth of field depending on adjustable iris setting. Shutter speed control is available. Length scales are PI-provided.	SRED does not specify number of views. *Modulation requirement not in the SRED* *Radiance values not provided in SRED*

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	N/A		
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	N/A		

Requirement Type: *Experiment Measurements*	SRD Requirements for c1: *Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)*	FCF Capability	Compliance Comments
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate	Eight point measurements located at selected locations above the nozzle tip (1.5 to 15.0 cm) and from the nozzle centerline (0 to 5 cm). The positions shall be within +/- 2 mm and known to within +/- 1 mm of the required values. Range of 300 to 1500 K. Accuracy of 5 K at 300 K to around 45 K at 1500 K. Precision of +/- 2 K. Sampling rate of 30 samples/sec required, 50 samples/sec desired. Time constant to be less than 0.3 sec and to be measured.	PI-provided H/W in CIA	
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate	N/A		
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	One measurement. Located close to the chamber walls. Sampling rate of at least 1 sample/sec. Range of 0.05 to 2.5 atm. Accuracy of +/- 0.01 atm at 1.0 atm.	CIR-provided. Pressure data collected via FCU	

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**
Chemical composition Species Range Accuracy	Analysis of the burned gas sample. Species of most interest are CO, CO2, O2, and propane. Accuracy within 5% of reading. Other desired species are NO, NO2, and N2. Accuracy within 10% of reading. Particulate residues deposited on the mesh or any thermocouples are of interest.	GC-provided. Need to know the concentration range of gases to be detected and overall composition of gas mixture to perform GC calibration. Detection of N2, CO2 and O2 supported with an accuracy of 5% of reading. Propane, NO, NO2 and CO accuracies will be better than 10%.	[SRD has listed as post-flight].
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity	N/A		
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity	Measurements at three regions. Two of the locations are thin slices 1) 2 cm above the nozzle exit and 2) 8 cm above the nozzle exit. FOV at r = 2.5 cm is 0.5 +/- 0.1 cm high by 4.5 cm wide. One location to view entire flame region, located centrally at 7 to 10 cm above the nozzle tip. FOV of 20 cm dia. All radiometers located at least 10 cm from the nozzle centerline. Center of the detector surface shall be known to +/- 1 mm. All FOV shall be known. Sampling rate of 30 Hz. Wavelength between 0.3 and 10 microns. Time constant shall be known, and measured in ground tests.	PI-provided H/W could be part of CIA or located outside the chamber at any available UML. CIR provides window with transmission in the required radiometer detection range	

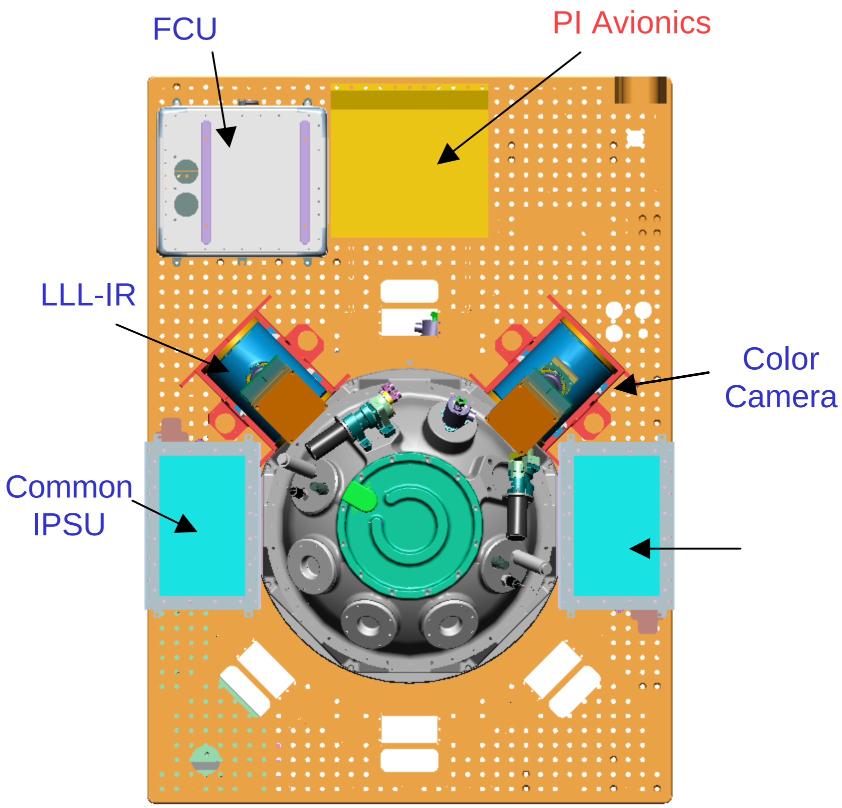
Requirement Type: ***Experiment Measurements***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles	N/A		
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles	N/A		
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate	Tri-axial measurements over the range of 10-3 to 10-5 g in the vicinity of the experiment chamber. One axis aligned with the nozzle axis. The other two axes are desired to be aligned with the cameras. Sampling rate of 30 Hz.	SAMS triaxial sensor head provided	
Other Experiment Measurements			

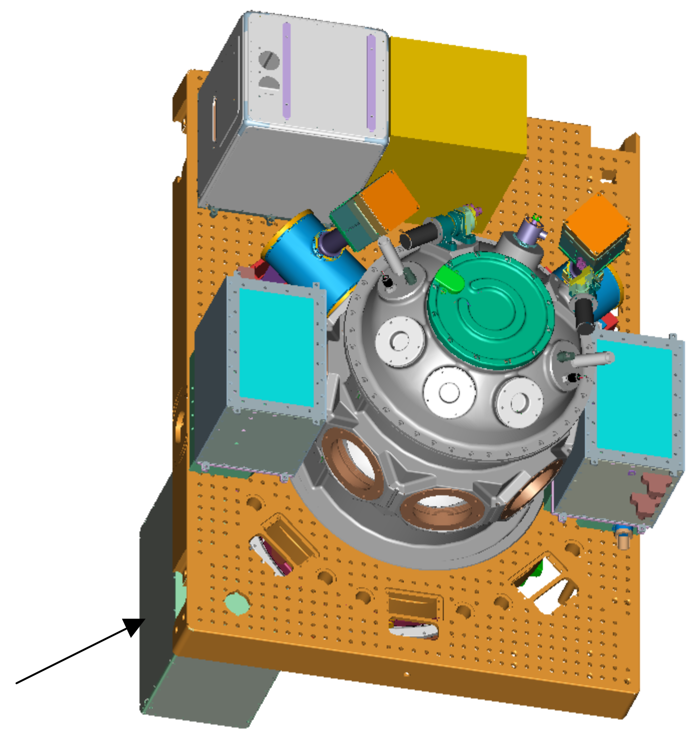
Requirement Type: ***Data Management***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All measurements shall be correlated to a single origin in time with an accuracy of at least 0.004 second. It is acceptable to correlate the video signals to the same time original with an accuracy of 1/30 sec, although 1/60 sec is highly desired. All digital data should be sampled simultaneously in periods no longer than 0.004 sec. It is also desired that both imaging views be sampled along with digital data.	CIR complies	*Requirement not specified in the SRED*
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.	Field: 2 cameras Single sensor: temperature (8), pressure, radiometer (3) Fuel flow, ignitor energy, acceleration, gas composition.	CIR provides 4 simultaneous cameras PI must supply means to measure temperature, radiometer data and ignitor energy	
Other Data Management			

Requirement Type: ***Operations***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing			
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)			
Auxiliary data Primary environmental parameters ISS data			
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points		All data can be downlinked. Fuel flow control available though FCU command between tests points. Ignition duration, iris freq. and length of pulsation controlled by PI electronics enclosure via chamber IRR.	[Would want to downlink all data. Would want to control Fuel flow, Ignition duration, iris frequency, and length of pulsation and rest times].

Requirement Type: ***Operations***	**SRD Requirements for c1:** ***Effects of Buoyancy on Transitional/Turbulent Gas Jet Diffusion Flames (TGDF)***	**FCF Capability**	**Compliance Comments**
Crew operations Crew observations during sample exchange Crew observations during test runs Other			
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points	Experiment timeline should have at least 15 seconds following ignition for the undisturbed flame to reach quasi-steady state, period of 10 seconds with pulsations at each of the prescribed frequencies, and period of 5 seconds between pulsations at different frequencies to allow the flame to adjust back to the undisturbed situation.	CIR color camera total run time capability is 27 minutes; Intensified camera total run time is 20 minutes.	
Post-flight sample and hardware return	Mesh and thermocouples returned for particulate residue analysis for size and composition.		
Other Operations			

Proposed diagnostics layout





Science Requirements Document Summary for

Structure of Flame Balls at Low Lewis-number (SOFBALL) (c2)

SRD Date: October 11, 1994

Principal Investigator: Prof. Paul D. Ronney
Project Scientist: Dr. Karen J. Weiland
Project Manager: Ms. Ann P. Over

Experiment Objective:

The objective of the SOFBALL experiment is to study the behavior of premixed flame phenomena called "flame balls." These phenomena are observed in weakly burning mixtures having a low Lewis-number. The results will be compared to theoretical models of these phenomena. The proposed experiments may yield an improved understanding of the ways in which buoyancy influences flame propagation and interactions between transport effects and chemical reactions. These studies may be applied to earth-based combustion science and spacecraft fire prevention and suppression.

Experiment Summary:

A combustion chamber is filled with a premixed combustible mixture and ignited with a spark. The resulting flame balls and other structure form and propagate slowly throughout the chamber. The length of burn time, flame shape, structure, and intensity, and pressure, temperature, flame radiation, and amount of fuel and oxygen consumed are measured.

Requirement Type: *Experiment Operating Conditions*	SRD Requirement for c2: *Structure of Flame Balls at Low Lewis-number (SOFBALL)*	FCF Capability	Compliance Comments
Test Section Dimensions Volume Dimensions Shape	For cylindrical chamber inside diameter shall be at least 32 cm. [4.1.2] Combustion volume diameter nearly equal to length (SRD4.1.2) Combustion gas volume equal to or greater than 25 liters. [4.1.2] Chamber wall emissivity greater than or equal to 0.8 at wavelengths from 2 microns to 25 microns [4.1.2]. In addition, wall absorptivity shall be greater than 0.9 at wavelengths (0.4 microns to 0.9 microns) detectable by flame imaging system. Chamber should have 30 cm clear field of view except for thermocouples and igniter. [4.1.2] Window material and coatings shall be selected to be compatible with imaging requirements. [4.1.2] Ambient light shall be excluded from entering chamber. [4.2.1] Maintain chamber wall temperature constant to ±0.04 K during the test. [2.4.5.3]	CIR chamber is 39.6 cm.; 90L free volume No chamber wall finish requirements in SRED Maximum clear field at least 30 cm Window material and coating compatible with imaging requirements. Window openings will be suitably shielded	[Experiment Mounting Structure] *No chamber wall finish requirement in SRED*
Fuel State Physical state of fuel Storage Distribution Mixing Handling	H_2 - 4.00 O_2 - 20.17 N_2 - 75.83 to H_2 - 3.35 O_2 - 20.30 N_2 - 76.35 1atm H_2 - 6.00 O_2 - 12.00 CO_2 - 82.00 to H_2 - 4.33 O_2 - 8.67 CO_2 - 87.00 1atm H_2 - 7.67 O_2 - 15.33 SF_6 - 77.00 to H_2 - 6.33 O_2 - 12.67 SF_6 - 81.00 1 and 3 atm The gases must be thoroughly mixed and of known composition, as defined in the test matrix with a concentration accuracy of ±2% of percentage composition. [4.1.3] H_2. Purity: greater than 99%. [4.1.3, 4.3]	Pure fuels can be delivered from the fuel/premixed fuel supply manifold and mixed the oxidizer and diluent delivered from combinations of the remaining three manifolds in either 1, 2.25 or 3.8 L bottles	[CM-1 had 14 premixed bottles for 15 test points (one repeat) Accuracy is 2% of each component, e.g. 4.00% +/- 0.08%].

Requirement Type: *Experiment Operating Conditions*	SRD Requirement for c2: *Structure of Flame Balls at Low Lewis-number (SOFBALL)*	FCF Capability	Compliance Comments
Ignition Igniter Power Control Geometry	Spark Igniter shall be at chamber center with electrodes perpendicular to viewing axis. [4.1.4] Spark gap must be adjustable from 0.1 to 1.0 cm (accuracy 10%) between tests. If spark does not fire, reduce spark gap by 25%. If this spark does not fire, reduce spark gap to 50% of initial gap. Diameter of electrode should be no greater than 0.35 mm for a distance of 40 mm from tip. Igniter should not be retracted. Spark energy: Adjustable from 0.025 to 0.4 Joule. Accuracy: ±25% [4.1.4.1] Energy deposition for each set of conditions must be calibrated. Spark duration: Less than 0.05 seconds. Provide a means to indicate whether the spark fired. [4.1.4.2] Provide capability for 3 ignition (respark) attempts at increasing energy up to 4 times the nominal ignition energy. The time between each attempt at ignition should be at least two minutes. [4.1.4.3] Spark igniter support structure shall provide a 40 mm minimum clear radius with respect to the point of ignition.	Spark ignitor: PI-provided. Chamber IRR electrical interface allows up to 16 A – 28V line delivered to CIA	[Spark ignitor on EMS. Spark energy Increased to 5 J, duration to 50 msec for reflight].
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	Acceleration Environment: A time average acceleration level of 4 x 10^{-4} go below 2 hertz; 1 x 10^{-4} g_o f^2 (f in hertz) above 2 hertz over the duration of the combustion test (up to 100 seconds). [4.5.1]	CIR will operate with an active ARIS.	[Found to be Inadequate on MSL-1. Lower Limits for Reflight].
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	All tests are performed at a constant volume at an initial pressure of 1 or 3 atm ±2%. [4.1.3, 4.3] Pressure drop due to gas sampling before combustion shall be less than 1%. [4.1.3]	CIR complies	

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Operating Temperature Gas temperature control Condensed phase fuel temperature control	Temperature: Initial gas temperature: 281 – 308 K. Preferred that all combustion tests be initiated when the gas temperature is within 10 K band within this range. [4.5.2]	Initial temperature depending on cabin air temperature range	
Oxidizer Composition Components Range Accuracy	In all cases, the oxidant is oxygen. Purity 99%. [4.1.3] Diluents are: N2, CO2, and SF6. Purity greater than 99% is required. [4.1.3 and 4.3]	Oxygen, CO2 and SF6 are PI-provided N2 is ISS-provided	
Fuel Flow Flow rate Range Duration Accuracy Stability	N/A		
Oxidizer Flow Flow rate Range Duration Accuracy Stability	N/A		

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Number, duration of tests	Perform 30 test points as detailed in the test matrix. Durations are on the order of 100 seconds. It is highly desirable that the test time not be fixed at 100 sec. Maximum possible test time is 500 sec. [SRD 3.1, 4.3, 4.4.2]	Maximum camera run time is 20 min. Rough estimate indicates that to support 20 test points PI will need: 6-1L fuel, 5-3.8L and 1-2.25L diluent; 1-1L O/N; 1-1L O/CO2 and 12-1L O/SF6 bottles.	*SRED App. B indicates 15 test points. Fig. C7 indicates 30 test points.*
Other Experiment Conditions	Combustion byproducts and unburned reactants may require venting to space [4.5.4]. For SF6 - diluted mixtures. . .potentially corrosive HF and SO2 in combustion products. Plan to measure in KC-135 tests. [4.1.2] If the mixture is to be reburned then the gas must be allowed to settle to mechanical equilibrium. SRD 2.4.7	CIR EVP provides venting to space prior to analyzing by-products for materials compatibilities as required by ISS	[Exhaust vent package filters].

Requirement Type: *Experiment Measurements*	SRD Requirement for c2: *Structure of Flame Balls at Low Lewis-number (SOFBALL)*	FCF Capability	Compliance Comments
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	Imaging/Visualization: Provide a scale for spatial correlation. Measurement tolerance: ±2% Two orthogonal views; at least one view orthogonal to a plane containing the spark electrodes is preferred. Depth of Field: 30 cm Field of View: 30 x 22.5 cm. for one camera. Desired for two cameras. [4.2.1] Framing Rate: 30 fps Provide digital imaging capabilities since higher resolution digital video recording will be available. Spatial Resolution: 2.2 mm at 50% MTF at center of chamber. Ensure the electronic shutter is closed or gain is set to low value during the spark firing to avoid damaging the intensifier or imager detector. Time is in the range from one standard frame (1/30 sec.) to several frames for high energy sparks and can be effectively determined in ground tests. [3.3.1-9] Measure flame intensity to within ±20%. Required camera characteristic: signal to noise ratio at least 10. Low luminosity flames should produce, after digitization, at least 9 readable gray levels between pure black and the Measure flame intensity to within ±20%. Required camera characteristic: signal to noise ratio at least 10. Low luminosity flames should produce, after digitization, at least 9 readable gray levels between pure black and the maximum intensity of the flame. PI comment: . . .a factor of approximately 5 increase in sensitivity may be needed to meet the specified resolution for flight tests (compared to KC-135 tests). [3.3.1] Visualization Method: Intensified near-IR (700-900 nm) video. Provide filter in front of each intensified camera. 800 nm long pass filter.	Spatial correlation will be done on the ground (or it could be PI-provided). PI CIA must be designed to be aligned with appropriate windows 1 near-IR Low Light Level Package provided: Resolution and depth of field depending on zoom and iris setting 30fps; 212mm sq. FOV; 417µm resolution at full aperture and max. FOV. Autofocus available. Depth is 4cm. at maximum FOV. Camera will be gated. 12-bit digital output (4.4x10E-9 ft-candle sensitivity). 500-875 nm spectral range at 50% of peak sensitivity. 800 nm long pass filter is PI-provided. Camera package will accept filter. 1 color camera package provided 400-1050 nm spectral range. 2 lux sensitivity; 8-bit digital output. Camera sensor is not damaged by intense illumination. 30fps 350 to 58 mm sq. FOV; depth of field is 5cm. at 30cm. FOV 1.2mm resolution at full aperture and req. FOV	Requirement for spatial correlation not in SRED. SRED does not specify number of views. [Color cameras also used for spark detection]. *Modulation requirement not in SRED.* *SRED does not provide radiometric accuracy requirements on the imaging systems.*

Requirement Type: ***Experiment Measurements***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	N/A		
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	N/A	CIR provides one UV Low Light Level Camera 280-700nm spectral range. Filter is CIR-provided. 30 fps 12bit digital output. Could be placed Orthogonal to near IR LLL camera 20 min. max. run time. FOV and DOF specifications identical to near IR LLL unit	[PI interested in OH emission imaging and showed feasibility in 1998 KC-135 flights. Requirements same as visible imaging but with 310 nm filter].

Requirement Type: ***Experiment Measurements***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate	Initial gas temperature: 281 – 308 K. Absolute accuracy ±5 K, repeatability ±2 K. Number of locations: 6 points. Locations: All points should be on the same side of the spark gap, with the closest point about 3 cm from the gap. Subsequent points should be spaced every 2.0 cm along an imaginary line passing through the center of the spark gap and the first measurement point. Change thermocouples on-orbit if necessary. Range of measurements: 300 K – 1400 K. Response time: 0.05 sec. Sample Rates: 20 Hz. Accuracy: Absolute ±50 K, repeatability: ±20 K. For initial measurements, absolute accuracy is ±5 K, repeatability ±2 K. Distance between rake supports: 150 mm minimum preferred. Spatial resolution: 0.02 cm. The location of each thermocouple should be known to within ±0.1 cm. If coatings are required on thermocouples, then the entire thermocouple, not just the bead, must be coated. Record temperature for 5 minutes at one or more of the 6 measurement locations at 1 Hz after other data acquisition has stopped.	Must be provided as PI H/W (CIA) Controls and data provided by PI Electronics Enclosure via Chamber IRR Electrical Interfaces	[Thermistors on EMS]. [Thermocouple rake on EMS].
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate	N/A		

Requirement Type: ***Experiment Measurements***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	Number of locations: One Range of measurement: 0.7 atm to 4.9 atm. Response time: 0.05 seconds. Sampling rate: 20 per second. [4.2.3(c)] Accuracy ±2% of reading. Pressure Data Requirements: Precision: ±0.4% of reading. Location: Out of field of view, flush with chamber wall. Non-intrusive. [4.2.3(e)] Duration: Length of test plus 5 minutes at 1 Hz. [4.2.3(c)]	Pressure transducers provided in chamber wall. Precision and frequency in compliance with requirement.	
Chemical composition Species Range Accuracy	Gas Sampling/Species Distribution: (Enhancement but not required): Sample before and after the test or sample after if only one can be taken on orbit. Take sample after gases are uniformly mixed. Range of composition to be measured: 0.1-100%. Accuracy: ±2% of reading. Components: H_2, O_2, CO_2, H_2O, SF_6, N_2 and CO. [4.2.6]	GC is CIR-provided ±2% of reading accuracy	[Gas Chromatograph]
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity	N/A		

Requirement Type: ***Experiment Measurements***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity	Number of locations: 1 required, 4 desired. If 4 are installed then they should be in pairs on opposite sides of the combustion chamber. Range of measurements: 10-5 to 10-2 W/cm2; wavelength range from 2 to 25 microns. It is desirable to install the radiometers in pairs with a 5.0 to 7.5 µm band-pass filter over one radiometer in each pair. Range of measurement with filter is 10-5 to 10-3 W/cm2. Response time: 0.1 seconds. Accuracy: ±20% of reading. Location: Any near-wall location, as nearly flush with the wall as practical. If two radiometers are employed, they should be installed on opposite sides of the chamber. Field of view: Goal is to encompass as much of chamber as possible. Gain: Autoranging gain is preferred (because location of flame balls cannot be predicted and location strongly effects incident radiation). If fixed gain is used gain setting for each mixture must be determined by KC-135 tests. Angular acceptance: There is no requirement on angular acceptance, however, the angular acceptance of the instrument must be known. Sensitivity and end-to-end resolution: The sensitivity shall be better than 2 x 10 EXP-6 W/cm2 and the end to end resolution at least 10 bits. [2.4.5.3]	Radiometers are PI-provided (CIA).	[Four radiometers on the CIA].
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles	N/A		

Requirement Type: ***Experiment Measurements***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles	N/A		
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate	Vibration/Acceleration Data: Axes: 3 orthogonal axes. Location: Near the combustion chamber. (Precise location is not required.) Sampling rate: 50 sps per axis during the experiment. Accuracy: ±10% of reading. Range: 10-5 to 0.05 g.	Acceleration Measurements provided via SAMS triaxial head	[Lower requirements for reflight. OARE data preferred].
Other Experiment Measurements			

Requirement Type: *Data Management*	SRD Requirement for c2: *Structure of Flame Balls at Low Lewis-number (SOFBALL)*	FCF Capability	Compliance Comments
Data Time Resolution Time resolution Time synchronization	All science digital data should be time correlated to 0.002 sec. All video data, analog and digital, should be correlated to 0.02 sec.	CIR complies	
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.	Field 2: Intensified visible imaging. Single sensor 11: Temperature 6, radiometer 4, pressure 1	CIR can operate UV and IR LLL and color cameras simultaneously. Camera gains will be recorded. Pressure Measurement provided by IOP via FCU. Temperature and radiometer data obtained by PI electronic enclosure	[Additional single sensors are a pressure transducer and four thermistors to total 16. Additional readings are Xybion camera gains and the spark gap.]
Other Data Management			

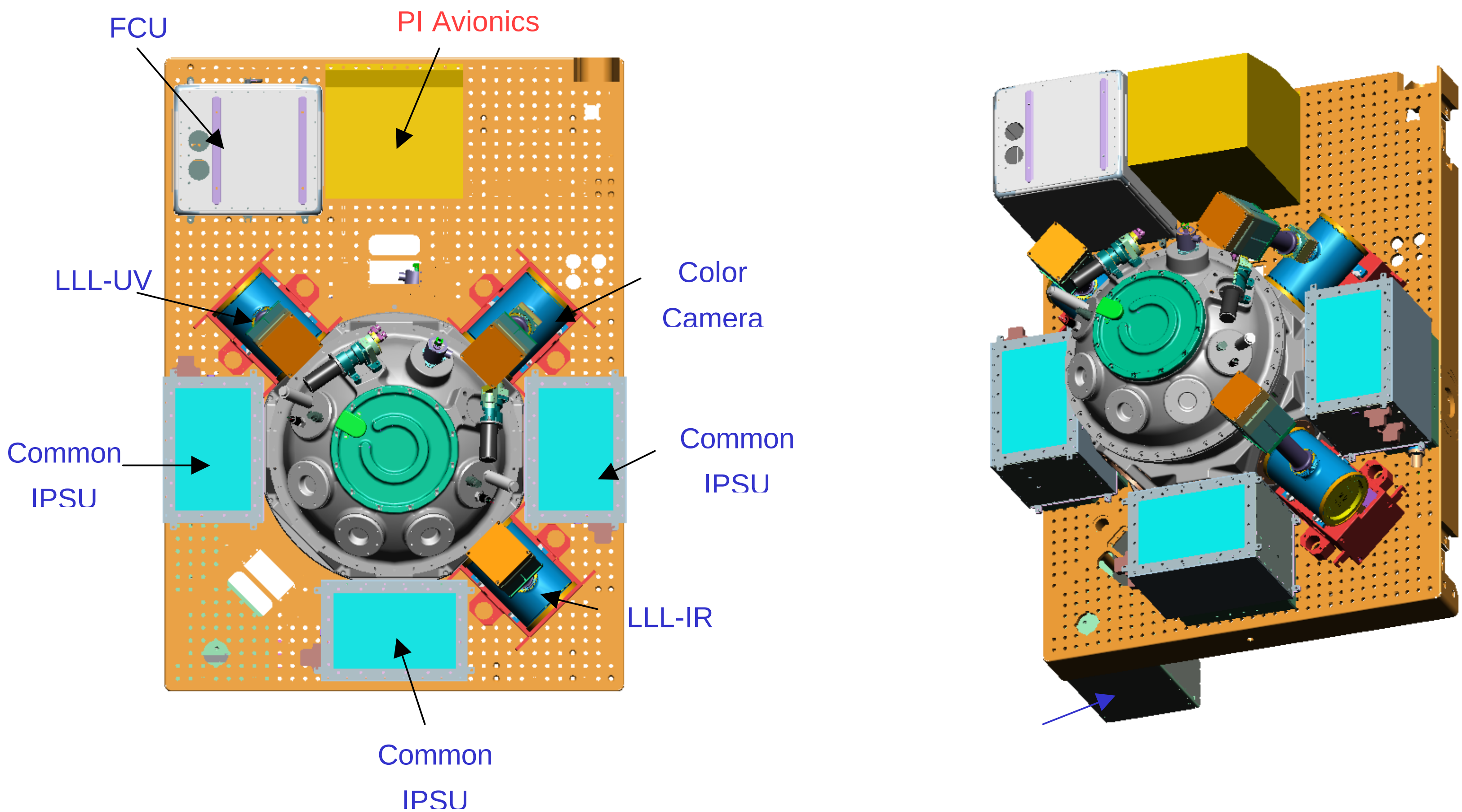
Requirement Type: ***Operations***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing		FCF provides CIR EDU and GIU for ground testing/simulations	[CM-1 conducted several pre-ship mission simulations running through various test point sequences]
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)	Verify camera operation, radiometer operation, and ignitor electrode holder location on monitor before each test. [4.1.2] Assess distortions caused by the imaging system. [3.3.1-9] Measure spark energy. Post Flight Gas Analysis: The premixed gases shall be analyzed after the mission. The sample shall be taken from the unused portion of the gases in the supply bottles. There are no requirements for timeline, sample containment, nor location of analysis	On-orbit verification is planned. Imaging system distortion will be assessed prior to CIR launch Provided by PI (PI electronics enclosure) N/A if on-orbit mixing is performed	
Auxiliary data Primary environmental parameters ISS data			

Requirement Type: ***Operations***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points	Tests to be performed in groups of 5 with a minimum of 6 hours between each group. Downlinking of data from the first test of each group is required. Required to have the capability to downlink test data from the mixtures in each group most likely to be reburned (includes five test points of first group). [4.4.1, 4.4.4] If gas composition data are downlinked in the form of unprocessed GC data, then ground support in the form of GC analysis is required. If reburn capability is available and not automatically invoked based on a pre-set criterion such as the test numbers, then the gas composition data is the second most desirable data for downlinking. [4.4.4] Downlinking need not be real time but for each group of five test points should be completed at least six hours before the next group is initiated. [4.4.4] The most important data for downlinking is at least one channel of intensified video, with (in order of preference) the pressure, radiometer, and temperature data also desirable. [4.4.4] The mission timeline should be planned such that for the test points for which reburning is most likely to be invoked (tests 3abc, 7ab, 11ab, 15) the latency of downlinking does not exceed one hour. [4.4.4] For all downlinking it is acceptable to abbreviate the quantitative data but not the video data. [4.4.4]	Downlinking frequency capabilities are TBD CIR is capable of downlinking all data	

Requirement Type: ***Operations***	**SRD Requirement for c2:** ***Structure of Flame Balls at Low Lewis-number (SOFBALL)***	**FCF Capability**	**Compliance Comments**
Crew operations Crew observations during sample exchange Crew observations during test runs Other	Reburn Procedure: The decision to reburn could be made by the PI or crew member after a test is completed (depends on amount of fuel consumed). Reburns are most likely for tests 3, 7, 11, and 15. [4.1.4.4, 4.4.4] Provide a means of adjusting camera gain via crew view of combustion event on monitor and record gain settings. It is desirable to have video modulation level indicator to help crew member set best gain. In-Flight Data Display: During the combustion tests, it is required that the video from at least one of the two intensified cameras be displayed. In-Flight Data Display: A continuously up-dated display of the following numerical data is desirable: a) Value of temperature from the location currently reading the highest temperature, and peak temperature from any location other than that closest to the spark electrodes since 5 seconds after ignition. [3.4.3] b) Current and peak chamber pressure. [3.4.3] c) Value of heat flux from radiometer currently giving highest output, and peak output from either radiometer since 5 seconds after ignition. For the H2-air tests, only the data from the radiometer with filters should be considered. [3.4.3] d) Status (pass or fail) for determination of whether a spark has fired based on spark current sensor. [3.4.3] e) Status (pass or fail) for determination of whether a mixture has ignited (section 4.4.2, t = 15 min) based o the temperature, pressure, and radiometer data. [3.4.3] f) Status (pass or fail) for determination of whether an ignite mixture has extinguished (section 4.4.2, t = 17 min) based on the temperature, pressure and radiometer data. [3.4.3] Crew involvement is required to determine if the ignition was successful and, if successful, when combustion event has been completed. Task 1) might not required crew involvement if a video downlink. [3.4.5.3] Crew involvement is required to diagnose and repair malfunctioning equipment. Most other events could be automated and indeed are automated in current ground-based apparatus Crew involvement is required to verify operation of all diagnostic hardware except accelerometers before each test. [3.3] [SRD 4.2]	False color display could be implemented for visualization from the ground at PI or TSC site Camera gain can be set as automatic or uplinked. Crew will have the ability to view only one video channel via the FLAP. To minimize crew intervention, all adjustable parameters will be uplinked prior to a test run. All in-flight data will be displayed on the ground via telemetry. Maintenance activities will be conducted by the crew with assistance from the ground Failures will be detected by a combination of BIT/BITE and ground controller observation Majority of the diagnostic H/W functions will be verified in an automated self-test sequence.	[False color display on video monitor for video level indicator].

Requirement Type: Operations	SRD Requirement for c2: *Structure of Flame Balls at Low Lewis-number (SOFBALL)*	FCF Capability	Compliance Comments
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points	Test Matrix: 2. Preference is to perform tests in the following order, First Flight: 3a, 7a, 11a, 15, 3b, 7b, 4, 1, 6, 2, 11b, 14, 8, 10, 12; Second Flight: 3c, 5, 9, 13, 16-26. It is desirable to be able to change test order. [4.4.1] Tests to be performed in groups of 5 with a minimum of 6 hours between each group. It is desirable to be able to change on-orbit the mixtures that are reburned without increasing their total number beyond the seven specified for the first flight. [SRD 4.4.1] Reburn Procedure: The decision to reburn could be made by the PI or crew member after a test is completed (depends on amount of fuel consumed). Reburns are most likely for tests 3, 7, 11, and 15. [4.1.4.4, 4.4.4]	Test point sequencing to be revised based on CIR capabilities	CM-1 changed the order of test points to take advantage of extra time.
Post-flight sample and hardware return			[Gas bottles not evacuated but returned for post-flight sampling].
Other Operations	Crew Voice Recording: The PI has found in his KC-135 tests that a crew record time-correlated to the imaging and science data is a valuable "diagnostic". Thus, it is desired that this information be provided for the SOFBALL experiments. The information would probably be especially useful since it is not likely that all important CM-1 operations will occur during periods of contact with ground stations.	There is currently no CIR capability in place to provide this requirement. Experiment execution will be controlled from the ground due to limited crew availability.	*Requirement not in SRED.*

Proposed diagnostics layout



Science Requirements Document Summary for

Spread Across Liquids (SAL) (c3)

SRD Date: SRD for the Reflight Series (April 1996). Italicized text is changes from the SRD from the first flight for the reflight. Underlined text is changes required for CIR experiments compared to a sounding rocket.

Principal Investigator: Dr. Howard D. Ross

Project Scientist: Mr. Jack A. Salzman

Project Manager: Mr. Bill A. Sheredy

Experiment Objective:

To characterize how flames spread across liquid pools in a microgravity environment, compare the results to spread at Earth gravity and to develop a numerical model. The modeling and experimental data provide a more complete understanding of the mechanisms of flame spread and add to the knowledge of on-orbit and earth-bound fire behavior and fire hazards.

Experiment Summary:

Liquid fuel fills a rectangular channel, is allowed to reach quiescence, and then ignited at one end. Tests are usually conducted with a low air flow across the fuel surface. The flame spreads across the surface and extinguishes when the air flow ceases. Flame images, liquid and gas phase temperature, igniter temperature and power, wall temperature, pressure, liquid- and gas-phase velocity and flow visualization, and acceleration are measured.

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
Test Section Dimensions Volume Dimensions Shape	TRAY: Dimensions: *30 cm length x 2.5 cm height x 2 cm width; or 30 cm length x 2.5 cm height x 8 cm width; or 30 cm length x 0.25 cm height x 8 cm width.* Or 30 cm length x 0.25 height x 2 cm wide, or similar; including round up to 30 cm diameter. Wall Material: Schlieren Quality for narrow trays; PIV-quality for wide trays, must have sharp pinning edge at liquid surface Flow duct of 10 x 10 cm cross section over the full length of the channel. None for a round pool.	CIA PI-provided H/W	
Fuel State Physical state of fuel Storage Distribution Mixing Handling	Butanol, Propanol. *Ethanol, Methanol, Decane.* Volume in Tray Per Test: 150 +/- 0.75 cc *for 2 cm wide, 2.5 cm deep pools; 600 +/- 3 cc for 8 cm wide, 2.5 cm deep pools; 60 +/- 0.3 cc for 8 cm wide, 0.25 cm deep pools* Purity: Certified grade; bubbles must be less than 2% by volume at end of filling process	Pure fuels can be delivered from the fuel/premixed fuel supply manifold and mixed the oxidizer and diluent delivered from combinations of the remaining three manifolds in either 1, 2.25 or 3.8 L bottles	*SRED App. B lists fuels as butanol, propanol and decane only.*

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
Ignition Igniter Power Control Geometry	**HOT WIRE IGNITER #1**: Location: 1 mm (+/-0.5 mm) above, 1 cm (+/-0.2 cm) from end, parallel to and stretched across full width of tray Surface Temperature: at least 1300 C within 2 s of energizing wire and maintainable for 30 s at or above this temperature Suggested Material: Kanthal Commanding Control: switch on/off any number of times at 3 s intervals **HOT WIRE IGNITER #2**: Location: 1 mm (+/-0.5 mm) above, 1 cm (+/-0.2 cm) from opposite end, parallel to and stretched across full width of tray Surface Temperature: at least 1300 C within 2 s of energizing wire and maintainable for 1 minute at or above this temperature Suggested Material: Kanthal Commanding Control: switch on/off any number of times at 3 s intervals **HOT WIRE FOR ROUND POOL**: Location: 1 mm (+/- 0.5 mm) above surface in pool center. Coil type ignitor. Must meet other criteria as above.	Ignitor is PI-provided. Chamber IRR electrical interface allows up to 16 A – 28V line delivered to CIA	
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	Accelerations: less than 0.0005 g_o in all directions at frequencies less than 10 Hz	CIR will operate with an active ARIS	

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	Initial Pressure Setting: 1 atm (+/-.01 atm)	CIR complies	
Operating Temperature Gas temperature control Condensed phase fuel temperature control	Initial Average Temperature Setting: Nominal fuel temperature (+/- 2 C) Initial Temperature in Tray: 21 C (+/- 1 C) or 28 C (+/- 1 C) for butanol tests; 14 C (+/- 1 C) for propanol tests; Uniformity: +/- 0.5 C <u>Liquid temperature between 10 and 30 degrees C.</u>	Initial temperature depending on cabin air temperature range	
Oxidizer Composition Components Range Accuracy	Gas: Dry Air with 21 +/- 0.1% O_2; some known humidity is acceptable, is the standard. <u>Ability to test gas mixtures with O2 concentrations from 15% to 25%, with the balance N2, Ar, or He also required.</u>	Oxygen, CO2 and SF6 are PI-provided, N2 is ISS-provided	
Fuel Flow Flow rate Range Duration Accuracy Stability	NA		

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
Oxidizer Flow Flow rate Range Duration Accuracy Stability	Setting: 5 cm/s to 30 cm/s -- see Test Matrix Uniformity: +/-10% of the nominal setting outside the boundary layer Region of Interest: cross-section - 0 to 7.0 cm above fuel surface. *1 cm on each side of tray for the narrow tray, and full duct width for wide tray; full length of the tray*. Commanding Control: switch on/off any number of times at 5 s intervals	Based on the 10 x 10 cm duct, max FOMA flow velocity is 15 cm/s.	*SRED App. B indicates max velocity of 50 cm./s* *Experiment re-circulation fan would be required for velocities over 15 cm/s.* *Flow duration is not specified. SRED Fig C7 indicates 3000 s; FOMA can only flow at 5 cm/s for that duration.*
Number, duration of tests	7 tests. <u>CIR test number is TBD.</u>		
Other Experiment Conditions			

Requirement Type: *Experiment Measurements*	SRD Requirements for c3: *Spread Across Liquids (SAL)*	FCF Capability	Compliance Comments
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	FLAME IMAGING: Number of Views: 2 Orientation: 1 side view and 1 top view of tray Side View Region of Interest: Full axial length x 5 cm above top of tray and 1 cm into pool depth; *for wide pools, this may be modified based on test results* Top View Region of Interest: Full axial length x 1 cm on each side of tray width; *for wide pools, this may be modified based on test results* Color or B/W: Color *(side), B/W (top); B/W for lower light use* Resolution: Standard, available video camera/recording systems should be adequate Low Light Sensitivity: 3 lux or better; must be able to clearly see blue leading edge of flame; no automatic gain control Minimum Framing Rate: 30 frames/s A view of tray filling is required for both post-flight analysis and planning for subsequent test points and to decide on the timing of ignition during the test. This includes having adequate lighting for the tests. See temperature field measurements of liquid or gas phase for Rainbow Schlieren imager.	One color is provided for side view. Color camera min. sensitivity is 2 lux, 30 fps 35 to 5.8 cm sq. FOV B/W camera is LLL (near IR and visible). 21.2 to 4.2 cm sq. FOV. 30 fps. 400 to 900 nm spectral range. The FOV will cover about 70% of the length for top view.	[Sounding rocket had two cameras for each view to cover the length of the tray].

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	See temperature field measurements of surface.		
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration			

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate	LIQUID AND GAS-PHASE TEMPERATURE (POINT): Rake 1: 5 Sensors at Height: 2.0, 2.25, 2.5 cm, 2.6 cm, and 3.0 cm from bottom of tray Axial: 2 cm (+/- 0.5 mm) from igniter #1 end of tray Width: 1-2 mm off centerline (+/- 1 mm) Rake 2: 3 Sensors at Height: 2.0, 2.25, 2.5 cm from bottom of tray Axial: 19.5 cm (+/- 2 cm) from igniter #1 end of tray. These sensors must be in the schlieren FOV. Width: 1-2 mm off centerline (+/- 1 mm) Rake 3: 2 Sensors at Height: 2.6 cm and 5 cm from bottom of tray Axial: 1-2 cm (+/- 0.5 cm) upstream of pool Width: non-interfering with other measurements Rake 4: 2 Sensors at Height: 2.6 cm and 5 cm from bottom of tray Axial: 1-2 cm (+/- 0.5 cm) downstream of pool Width: non-interfering with other measurements RSD reference: 1 Sensor near bottom of pool in RSD field of view Sampling Frequency: 30 to 33 Hz in liquid; 30 to 33 Hz in gas Accuracy: 0.25 C in liquid; 1 C (<100 C) and 1% (>100 C) in gas Time Response: <= 5 ms in liquid; <= 50 ms in gas	Temperature point measurements are PI-provided	

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
	SOLID-PHASE TEMPERATURES (POINT): Location: 1 Sensor on inner surface of tray end wall near igniter Height: 2.3 cm from bottom of tray; Width: centerline (+/- 0.1 cm) Location: 1 Sensor on inner surface of tray side wall Height: 2.3 cm from bottom of tray; Axial: Same as Rake 3 Location: 1 Sensor on inner surface of shroud wall Height: 2 cm above pool top Axial: 1 cm outside rainbow schlieren field of view (21 cm from igniter end) Width: approximately flush with inside surface of shroud Sampling Frequency: 30 to 33 Hz Precision: 1 C (<100 C) and 1% (>100 C) Note: The sensors specified are for the narrow/deep tray. Other sensor configurations may be used on other trays that would be supplied by the PI. This may be considered an upper limit on the number of sensors used in the tray.		

Requirement Type: *Experiment Measurements*	SRD Requirements for c3: *Spread Across Liquids (SAL)*	FCF Capability	Compliance Comments
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate	LIQUID AND GAS-PHASE TEMPERATURE (FIELD) -- [RAINBOW SCHLIEREN]: Region of Interest: height: 10 cm diameter FOV centered on fuel surface Axial: 10 cm diameter FOV centered at midpoint of tray. Due to the mirrors' clear aperture constraints, and imperfect imaging of the schlieren beam onto the CCD array, an effective FOV of 9.5 cm can be tolerated. Sampling Freq.: 30 frames/s Spatial Resol.: 0.2 mm Accuracy: 0.2 C in liquid; 50 C in gas (desired) Range: 50 C in liquid; 1500 C in gas (desired) *For wide trays, the primary interest is the gas phase; for narrow trays, the primary interest is the liquid phase.* No RSD is needed for round pools. LIQUID SURFACE TEMPERATURE (FIELD) -- [IR IMAGING]: Region of Interest: *7.5 cm along axis x full width of tray* Sampling Freq.: 30 frames/s Spatial Resolution: 0.2 mm Precision: 0.25 C	PI-provided Long IR imaging system is PI-provided	

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	Range: 0 to 1.5 atm Precision: 0.01 atm Location: non-interfering with other measurements Sampling Frequency: 10 - 20 Hz	CIR complies	
Chemical composition Species Range Accuracy			
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity			
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity			

Requirement Type: *Experiment Measurements*	SRD Requirements for c3: ***Spread Across Liquids (SAL)***	FCF Capability	Compliance Comments
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles	*GAS VELOCITY (point measurement) -- desired* *Location: Duct inlet, near sidewall. It is desired to measure the inlet velocity during flame spread, mainly to look for changes. Either a hot wire probe or a mechanical indicator is acceptable.*	PI-provided (CIA)	
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles	LIQUID VELOCITY (Particle Imaging): Location: *See attached figure* Framing Rate: 30 frames/s Tracer Particles: *10 micron optical grinding powder (Optiforce 1800)* GAS VELOCITY (Smoke/particle Imaging): Location: *See attached figure* Framing Rate: 30 frames/s Tracer Particles: *Smoke issuing from hot wires installed upstream of pool. Coated with either oil or a solid that can be pyrolyzed. Exact orientation and number of wires (about 5) are TBD. These will be pulsed electrically at up to 10 intervals on the order of 0.25 to 1 Hz for a period of up to 25 seconds. Commanding is desired from the ground, however preprogramming is acceptable.* *Same cameras can be used for liquid-phase PIV.* *Alternatively, we will explore the use of microfeathers, per text.*	Top view: use LLL-UV camera for imaging system. 30fps PI provides illumination. Side view: use HFR/HR package operated at 30fps. PI provides illumination.	

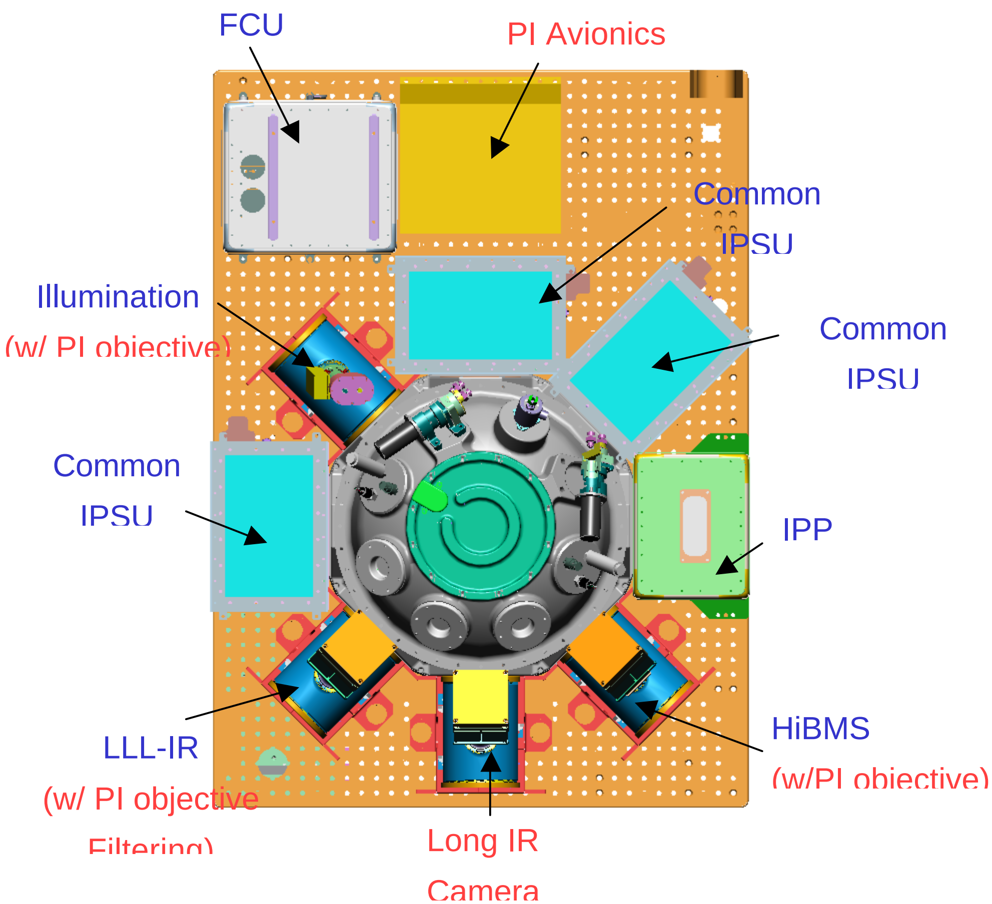
Requirement Type: ***Experiment Measurements***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***		**FCF Capability**	**Compliance Comments**
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate	Direction: Sampling Frequency: Precision:	All three principal axes 30 to 33 Hz 0.00005 g_o	Measurements taken using SAMS triaxial sensor. 10^{-9} g/g_0.	
Other Experiment Measurements	Igniter temperature and power input.		Means to measure igniter temperature and power input is PI-provided via PI Electronics Enclosure through chamber IRR.	

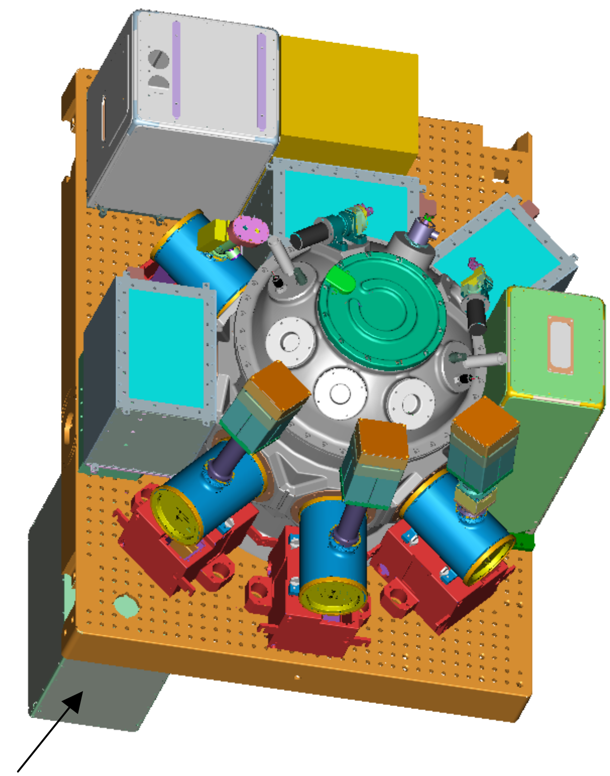
Requirement Type: *Data Management*	SRD Requirements for c3: *Spread Across Liquids (SAL)*	FCF Capability	Compliance Comments
Data Time Resolution Time resolution Time synchronization	All signals including video synchronized to within 0.005 s.	All video will be synchronized to 1ms	
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.	Field: (6-8) Top flame imaging view(s) of tray, Side flame imaging view(s) of tray, Top PIV view, Side PIV view and Rainbow Schlieren view (simultaneously), Side PIV narrow view, Top view infrared. Single sensor: (20) Pressure, 16 temperature, gas velocity, 2 ignitor power.	CIR can only support 4 simultaneous cameras. Need to configure the experiment locating the IPPs in the SAR. Additional IPP will be required.	
Other Data Management			

Requirement Type: ***Operations***	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing			
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)	Igniter temperature may be calibrated on the ground. <u>Scales for all view must be recorded. IR camera and RSD must be calibrated on the ground.</u>	PI development	
Auxiliary data Primary environmental parameters ISS data			
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points	Ground commanding of these functions during the test: switching on/off each igniter any number of times at approximately 3 s intervals; switching on/off the fan any number of times at approximately 5 s intervals; changing fan speeds between two preset values.	TBD	

Requirement Type: *Operations*	**SRD Requirements for c3:** ***Spread Across Liquids (SAL)***	**FCF Capability**	**Compliance Comments**
Crew operations Crew observations during sample exchange Crew observations during test runs Other			
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points	Experiment power on, mix fuel and PIV particles, fill fuel tray, fuel settling phase, turn on air flow, ignitor on, flame ignition and spread, collect data, extinguish flame by turning off the fan, allow surface to cool, turn on air flow, begin second burn, collect data, extinguish flame by turning off the fan.		
Post-flight sample and hardware return			
Other Operations			

Proposed diagnostics layout





Science Requirements Document Summary for

Flammability Diagrams of Combustible Materials in Microgravity (FIST) (c4)

SRD Date: January 1999

Principal Investigator: Prof. Carlos Fernandez-Pello

Project Scientist: Dr. Howard Ross

Project Manager: Jeff Jones

Experiment Objective:

To study the effects of gravity on the flammability diagrams of solid combustible materials and the fire properties derived from such diagrams. The specific objectives are to develop a new flammability apparatus that will better reflect the potential ambient conditions of space-based environments and to use the apparatus to obtain more appropriate flammability diagrams for common materials used in space facilities.

Experiment Summary:

The ignition of solid fuel samples as a function of external radiant flux, flow velocity, and oxygen concentration is studied in a small scale combustion wind tunnel. The wind tunnel is composed of an inlet section, test section, and an outlet section. The upper wall parallel to the fuel specimen is a radiant heat panel that provides an incident flux to the fuel. Once the sample is ignited by a Nichrome wire downstream from the fuel, the rate of flame spread as a function of the surface radiant flux is measured. The required measurements are of the gas velocity, oxygen concentration, temperature of the fuel, and visualization of the ignition (time to ignition) and flame spread rate. Exhaust gas measurements are desired. The CIR space experiment focuses on opposed flow flame spread.

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions Volume Dimensions Shape	Flow Duct and Test Section is 100 x 100 x 150 mm (length). Tolerance of +/- 5 mm on height and width; + 5 mm on length. Uniformity and measurement precision of +/- 1 mm. Solid wall material is to be heat-resistant. Side view in the visible and IR spectrum is to have 100% optical access of ignition and flame spread areas.	Flow duct and test section is PI-provided. Chamber can accommodate the required dimensions. Optical access available through 8 windows, each 110 mm clear aperture and replaceable with PI-provided windows if different spectral characteristics are required.	

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Fuel State Physical state of fuel Storage Distribution Mixing Handling	Fuel sample type 1) polymer such as PMMA and 2) composite. Ignition study sample size is 30 x 30 x 10 mm. Flame spread study sample size is longer, 100 x 30 x 10 mm. Fuel thickness is nominal 10 +/- 0.5 mm for polymers, TBD for composites. Uniformity +/- 0.5 mm; measurement precision +/- 0.25 mm. Fuel exposed width is 30 +/- 0.5 mm; uniformity of +/- 0.5 mm; measurement precision of +/- 0.25 mm. Fuel exposed length is 30 mm for ignition studies and 100 mm for flame spread studies. Tolerance of +/- 5 mm; uniformity of +/0 0.5 mm, measurement precision of +/- 0.5 mm. Sample ignition area is 30 x 30 mm for a single sample. Tolerance of +/- 0.5 mm; uniformity and measurement precision of +/- 0.25 mm. Sample flame spread area is 100 x 30 mm and uses first 20 mm for ignition. Tolerance of –0.5 mm; uniformity and measurement precision of +/- 0.25 mm. Sample holder is to be of low conductivity material, placed in the test section away from the boundary layer at the walls or as the floor of the duct. Minimize perturbations of gas flow. Minimize reflection of radiation. Sample is to be flush mounted with the top surface of the sample holder. Tolerance, uniformity, and measurement precision of +/- 0.1 mm. Sample thickness may be reduced to 5 mm at its edges. Sample is to be located 30 mm from the entrance of the test section and centered in the test section. Tolerance of +/- 1 mm; uniformity of +/- 0.5 mm; measurement precision of +/- 0.25 mm. Multiple samples are acceptable but with a separation of at least 20 mm between samples.	Fuel sample, sample holder and ignitor are PI-provided in CIA. Controls, power and data provided by PI electronic enclosure via chamber IRR. CIA must provide mechanism for multiple samples settings.	[Sample holder Is likely to extend into the test section inlet in order to minimize the flow disturbance].

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Ignition Igniter Power Control Geometry	Ignitor temperature must be above 1000 C, with a tolerance and measurement precision of +/- 50 C. Time on is at the radiant flux exposure of the sample. Time off is after flaming is confirmed or test time completed. Time to reach nominal temperature is less than 5 seconds. Ignitor wire axis should be perpendicular to the sample surface, a 5 mm diameter spiral, stretching to 10 mm over the plane of the sample surface.	Ignitor is PI-provided in CIA. CIR provides electrical interfaces via IRR (16A max current at 28 V max. voltage).	[Ignitor wire may be inserted through the bottom wall of the test section].
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	Limits will be the same as other solid fuel experiments, such as SIBAL.	CIR will be operated with an active ARIS. Acceleration measurements provided by SAMS triaxial sensor.	
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	1 atm. Tolerance of 0.2 atm. Uniformity of 0.2 atm.	Within the CIR operating pressure range	[Requirements will likely be reduced to 0.05 atm].
Operating Temperature Gas temperature control Condensed phase fuel temperature control	Fuel sample shall be at 21 C, +/- 5C, with a uniformity of +/- 0.25 C, and a measurement precision of +/- 0.25 C. Gas temperature shall be 21 C +/- 4 C. Uniformity of +/- 4 C.	Fuel sample and Gas temperature within the range of cabin temperature.	
Oxidizer Composition Components Range Accuracy	Either dry air or oxygen/nitrogen mixtures. Oxygen concentration 18 to 25%. Tolerance of +/- 0.5%. Uniformity of +/- 0.1%. Humidity shall be dry, with a tolerance and uniformity of +/- 10%.	O_2/N_2 mixtures can be provided from combinations of 1L 85%O_2, 2.25L 50%O_2 or 3.8L 30% O_2 and ISS-provided N_2	

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Fuel Flow Flow rate Range Duration Accuracy Stability	NA		
Oxidizer Flow Flow rate Range Duration Accuracy Stability	During the ignition tests, a recirculating gas flow could be used. During the flame spread tests, recirculation could be used prior to ignition of the sample. Gas velocity is from 50 to 200 mm/sec. Tolerance and uniformity of +/- 10%. Laminar flow with a tolerance for the turbulence intensity of 2%. Velocity profile requirement of a uniform profile at the entrance of the test section with tolerances of non-uniformity of less than 5%.	FOMA provides up to 90 SLM of dynamic flow through. For a flow duct of 10cmX10cm the max. Achievable flow velocity is 150mm/s. For recirculating flow, PI-provided fans or the FOMA clean-up loop that provides 20SLM max flow can be used.	[During the ignition tests a recirculating gas flow could be used. During the flame spread tests, recirculation could be used prior to ignition of the sample].
Number, duration of tests	Ten ignition type and six flame spread type tests for each of two fuels: total of 32 tests. Ignition tests will end when flaming ignition is observed. Flame spread tests will end when the flame front reaches 10 mm from the sample end. Test end can be determined through video images, infrared images, or thermocouples. A predetermined maximum time may also be used.	Visible and IR cameras are provided.	[Test end can be determined through video images, infrared images, or thermocouples] *Number of test points and durations are not specified in the SRED.*

Requirement Type: *Experiment Operating Conditions*	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Other Experiment Conditions: Radiant heating	Radiant heaters on one side of the fuel. Ignition studies will have a constant heat flux. Flame spread samples will have a spatially decaying heat flux. Heater fluxes are 10-50 kW/m2 and cover the complete ignition and flame spread areas. Control of heaters to be either on temperature or input power. Temperature sensor location at the center of the heater surface; power control sensor near heater leads. Sampling frequency 1Hz. Precision of 5C or 2% of power. Steady state is attained when temperature reaches +/- 5C of set value or power reaches 2% of set value. Ignition samples not to be exposed to radiance heater until it reaches steady state. Then the sample is to be exposed within 2 s. Nominal fluxes and distribution in test matrix charts in SRD. Estimated test time is up to 400 sec. Estimated total heater power is 130 to 310 W for the ignition tests and 140 to 1500 W for flame spread tests.	Radiant heater is PI-provided in CIA. Controls and power provided by PI electronic enclosure via chamber IRR. IRR max. power delivery capability is 448W Cameras run times are 20 min. or more.	

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	Flame imaging, Color: 1 side view Field of view 50 mm long and 20 mm high for ignition tests. FOV 100 mm long and 20 mm high for flame spread tests. Resolution of standard video recording, less than 1 mm in all axes. Depth of field 5 mm. Low light sensitivity of 3 lux or less, to see clearly any blue flames. 30 frames per sec Beginning 5 sec before sample is exposed to radiant flux. Ending for ignition tests 5 sec after test is ended, for flame spread tests, 60 sec after test is ended.	One color camera provided with zoom capability providing 58-350mm sq. FOV Resolution is 230μm at 58mm FOV and 390μm at 100mm FOV. 24 bit digital unit. Depth of field depending on aperture setting and FOV. Sensitivity 2 lux min. Spectral Range: 400-1050 nm. 30fps Camera on/off sequence can be uplinked. Total runtime capability is 27 min.	[Must block ignitor luminosity].
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	See 16.		

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	NA		
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate	Sample surface: 2 for ignition tests, junction in centerline, 10 mm and 15 mm from sample edge. 9 for flame spread tests, junction in centerline, 10 mm apart with the first located 20 mm from the trailing sample edge. Sampling frequency is 2 Hz. Precision is 5 C. Back Side sample: 1, junction in centerline in the sample back, 15 mm from sample edge. Sampling frequency is 2 Hz. Precision is 5 C. Gas Phase Temperature: 1 located in the vicinity of the ignitor, 5 mm from the surface. Sampling frequency is 1 Hz. Precision is 5 C.	All sample surface and gas temperature measurements are PI-provided via CIA.	Surface and back side can be Type K, 2 mils wire diameter, 4 mils bead size. Gas can be Type (Pt/Pt-Rh)

Requirement Type: *Experiment Measurements*	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate	Infrared imaging of fuel surface. 1 slanted or front view of entire sample surface. Spatial resolution 1 mm. Precision 5 C. Sampling frequency 30 frames/sec. View angle is not specified. Will need to accommodate radiant heaters.	CIR provides Mid-IR camera package. 183X138 mm FOV mm resolution 1-5µm spectral response Accuracy: 2C 12bit digital output up to 60fps	
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	Located in the test section non-interfering with other measurements. Range 0.2 atm. Precision 0.1 atm. Sampling frequency 1 Hz.	PI-provided in CIA	
Chemical composition Species Range Accuracy			
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity			

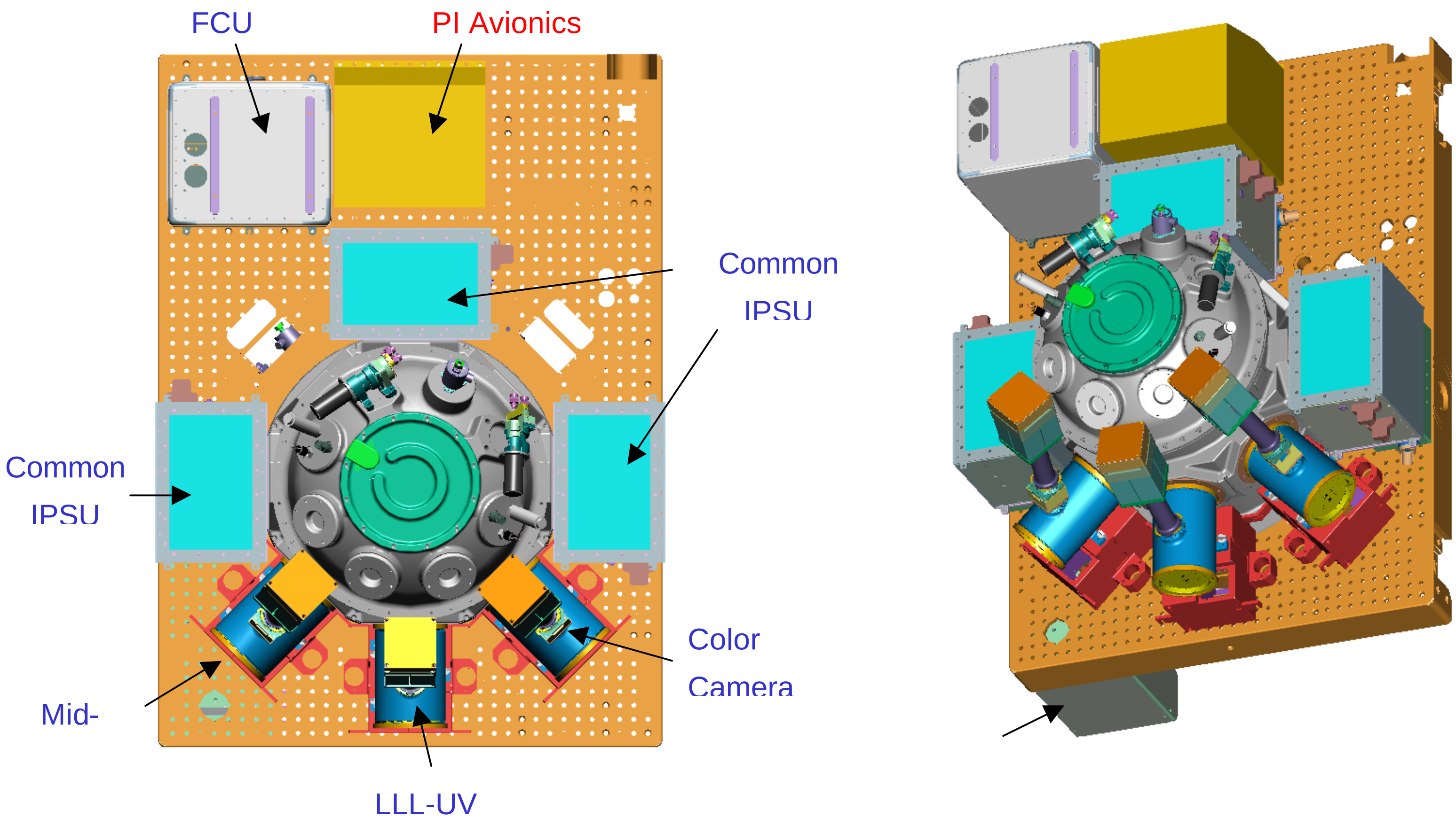
Requirement Type: ***Experiment Measurements***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity			
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles			
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles			
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate	Similar to those of other solid fuel experiments such as SIBAL. All three principal axes. Sampling frequency 10 Hz. Precision 5 $\times10^{-5}$ g.	Provided by SAMS triaxial sensor	
Other Experiment Measurements			

Requirement Type: ***Data Management***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data collected at least at a rate of 1 Hz.	CIR complies	
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.	Field: 2 - color and infrared images. Single sensor: Ignition tests: 6 - thermocouple (4), pressure, average flow velocity. Flame spread: 13 - thermocouple (11), pressure, average flow velocity.	All specified measurements can be provided simultaneously.	
Other Data Management			

Requirement Type: ***Operations***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing			
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)	Calibration of the radiant panels is to be done on the ground.	CIR GIU available for ground calibration	
Auxiliary data Primary environmental parameters ISS data			
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points	Downlink at least one video recording of the complete test for evaluation. Parameters requiring control include sample selection, flow velocity, oxygen concentration, heater power, ignition time, flame spread time, termination.	Downlinking available	

Requirement Type: ***Operations***	**SRD Requirements for c4:** ***Flammability Diagrams of Combustible Materials in Microgravity (FIST)***	**FCF Capabilities**	**Compliance Comments**
Crew operations Crew observations during sample exchange Crew observations during test runs Other	Crew required to observe video images and determine when steady state conditions have been attained for the heaters and the flame spread test samples. Crew required to observe when ignition has occurred and flame spread has reached the end of the sample and to terminate the test. These operations could be automated if necessary.	One camera output available for crew viewing on FLAP.	
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points	Ignition tests. Heaters to be energized without exposing the sample to any radiant flux. After they reach a steady state, the oxidizer gas is supplied through the flow duct. After flow and heaters are equilibrated, the fuels sample is exposed to the heaters and the ignitor switched on until ignition is achieved. Measurements are the piloted “flash ignition time,” flame imaging, surface temperature imaging, and thermocouples. Flame is extinguished and let system cool for next test point. Flame spread test: Sample exposed to heaters as soon as they are energized, without oxidizer flow. When fuel sample temperature reaches equilibrium the oxidizer gas is supposed and the igniter is energized. At the end of flame spread, extinguish the flame. Let system cool until next test point.	Recirculation and flow through capability provided. Could alternate via FCU control. Acceleration levels for these cases are TBD depending on vibration loads induced by EVP pump.	Recirculation of flow is possible during the preheating period, until just before fuel reaches a limit near the pyrolysis temperature. Then the flow is switched to a flow-through configuration.
Post-flight sample and hardware return	Samples to be returned to earth for weighing.		
Other Operations			

Proposed diagnostics layout



Science Requirements Document Summary for

Microgravity Smoldering Combustion (MSC) (c5)

SRD Date: April 1993 and August 1, 1997

Principal Investigator: Prof. Carlos Fernandez-Pello
Project Scientist: Dr. David L. Urban
Project Manager: Frank Vergilii

Experiment Objective:

To understand and predict smoldering combustion under normal and microgravity conditions. Smoldering is a fundamental combustion process that can play an important role in the initiation of unwanted fires.

Experiment Summary:

A porous combustible sample is heated until smoldering is achieved. The sample may be in a quiescent environment or in an opposed or forward forced flow. Smolder progress is tracked by temperature measurements taken throughout the sample and video images.

Requirement Type: *Experiment Operating Conditions*	SRD Requirements for c5: *Microgravity Smoldering Combustion (MSC)*	FCF Capabilities	Compliance Comments
Test Section Dimensions Volume Dimensions Shape	Pyrex or quartz cylinder sample holder. Foam to be compressed into holder to minimize flow around gaps. Initial foam sample diameter 10% larger than the nominal sample size. Minimum chamber volume of 20 L for quiescent cases or with the addition of new gas and not venting. If air is recirculated, then the minimum chamber volume is 30 L.	Sample holder PI-provided in CIA. CIR chamber free volume is 100L	
Fuel State Physical state of fuel Storage Distribution Mixing Handling	White, open cell, unretarded, polyurethane foam. Crain Industries Code #R-45165-0000 WHITE Cylindrical sample holder, 120 mm in diameter, 100 mm long. One fuel sample per test. Samples are 132 mm diameter, 154 long for encased samples and 120 mm diameter, 154 mm long for unencased samples.	PI-provided	
Ignition Igniter Power Control Geometry	Flat ceramic igniter with heater wire located at one end of the fuel sample. Dimensions of 120 mm diameter, 5 mm thickness. Power TBD. A layer of char 120 mm in diameter and 7.5 cm long is placed at the other end of the igniter. Slow flow of oxidizer at 0.1 mm/s +/- 10% for all tests to ensure a successful initiation of smolder in the foam.	PI-provided H/W	
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	Less than 10^{-3} times Earth gravity. Conduct experiments during time periods in which orbiter firings are not taking place.	Rack isolated by ARIS	

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c5:** ***Microgravity Smoldering Combustion (MSC)***	**FCF Capabilities**	**Compliance Comments**
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	1 atm +/- 10%. Initial pressure could be subatmospheric to bring the pressure to 1 atm at the end of ignition. Allowable to have the pressure increase during the oxidizer flow up to 3 atm.	Within CIR chamber operation pressure specifications	
Operating Temperature Gas temperature control Condensed phase fuel temperature control	Near 20 degrees C. Oxidizer temperature near the sample temperature, between 20 and24 C, but acceptable to be as low as 10 C. Required between 15.6 to 28 C; desired between 20 and 28 C. Sample uniformity of +/- 4 C about the average temperature. Temperature similar between different runs.	CIR provides oxidizer temperature in the range of cabin temperature	
Oxidizer Composition Components Range Accuracy	Initial humidity of 0 to 10%. Oxygen/nitrogen mixture with oxygen concentration range from 21 to 40%. Tolerance of +/- 0.5 mole %. Evacuation of chamber prior to filling to ensure that the foam pores contain the same gas composition as the ambient.	O2 and N2 can be mixed inside the chamber at the required concentration. Evacuation is possible at any time prior to testing vent gases.	*SRED Fig. C5a indicates 20-30% O2*
Fuel Flow Flow rate Range Duration Accuracy Stability	NA		

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c5:** ***Microgravity Smoldering Combustion (MSC)***	**FCF Capabilities**	**Compliance Comments**
Oxidizer Flow Flow rate Range Duration Accuracy Stability	Low-flow during ignition for all experiments is 0.1 mm/sec +/- 50%. Oxidizer flow from 0.3 to 7.0 mm/sec during the post-ignition period. Flow in opposed and countercurrent directions. Mass flow to be held constant to within +/- 5% based on the flow rate at 1 atm during cases of pressure increase. If a fan is used, the oxygen concentration must be monitored during the test. If recirculation used and for quiescent tests, minimum allowed oxygen concentration at the end of the test is 14%.	PI-provided CIA must be sized to allow for the required flow velocities. FOMA provides max. Inlet flow rate of 90SLM (1500cc/s). PI hardware must be able to provide flow direction capability.	*SRED App. B indicates 0-5 mm/s flow. Fig. C6 does not identify any flow rate.*
Number, duration of tests	4 in Phase I (two quiescent, two opposed); 8 in Phase II (two opposed, four countercurrent, two repeat). Test times up to 70 minutes. Maximum experiment time is 120 minutes.	Within the CIR capability	
Other Experiment Conditions			

Requirement Type: *Experiment Measurements*	SRD Requirements for c5: *Microgravity Smoldering Combustion (MSC)*	FCF Capabilities	Compliance Comments
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	Progress of the smolder reaction. Illumination required for seeing the smolder front. For quiescent, opposed, and low velocity forward smoldering, the field of view is the sample itself. Image resolution is such that the smolder reaction zone, which is of the order of 5 mm, can be identified. For higher flow velocity forward cases, the field of view should include the char to observe the potential transitions to flaming. Images to be acquired just prior to sample ignition and throughout the experiment. Image every 5 seconds through the 1 hour time duration of the experiment.	Illumination is PI-provided (CIA). Visible color and intensified near-IR (500-875nm) imaging is provided. Both units will provide a resolution better than 5mm for a FOV covering the sample. Cameras run time is well within test duration (over 4hrs for acquisition frequency of 1 frame every 5 sec)	
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration			

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c5:** ***Microgravity Smoldering Combustion (MSC)***	**FCF Capabilities**	**Compliance Comments**
Ultraviolet imaging			
Phenomenon of interest			
Framing rate			
Field of view			
Resolution			
Depth of field			
Sensitivity			
Wavelength(s)			
Duration			

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c5:** ***Microgravity Smoldering Combustion (MSC)***	**FCF Capabilities**	**Compliance Comments**
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate	Fuel sample interior (10 required): Used to determine the strength and progress of the smolder reaction. Inserted into the foam with stainless steel tubes. 7 are positioned with their junctions 12.5, 25, 40, 60, 80, 100, and 120 mm along the sample centerline. 3 off axis positioned at a distance of 60 mm from the igniter at 15, 25, and 35 mm from the centerline. Required spatial precision is +/- 0.5 mm unless position is measured after placement. Recommend that fine wire thermocouples be used, type K, with 1/32" sheaths. Range from 0 to 1000 C, with an accuracy of +/- 10 C. Measurements at intervals of 5 sec over the experiment duration of 1 hour. Ignitor surface (2 required): Used to determine the fuel ignition process and termination. Must be in contact with the ignitor outer ceramic surface. Alternative is to use unsheathed tc of same wire diameter but glued to ceramic. Recommend that fine wire thermocouples be used, type K. Range from 0 to 1000 C, with an accuracy of +/- 10 C. Measurements at intervals of 5 sec over the experiment duration of 1 hour. Chamber temperature (4 required): Range 0 to 40 C. Near the chamber wall or gas inlet. Precision of +/- 1 C, A/D conversion of 12 bit. Measurements at intervals of 5 sec over the experiment duration of 1 hour.	PI-provided H/W All controls, power and data provided by the PI electronic enclosure via chamber IRR electrical interfaces.	

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c5:** ***Microgravity Smoldering Combustion (MSC)***	**FCF Capabilities**	**Compliance Comments**
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate			
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	Record chamber pressure throughout the smolder process. Range 0 to 50 psia. Precision of +/- 0.1 psia. Measurements at intervals of 5 sec over the experiment duration of 1 hour, A/D conversion of 12 bit.	Chamber pressure sensors are CIR-provided	
Chemical composition Species Range Accuracy	Composition of oxygen, CO, CO2, N2, and CH4 in the chamber and at several locations in the interior of the sample. Oxygen sampling before and after the test is required to 1% of concentration accuracy. Oxygen measurements desired if the air is recirculated in the chamber. CO2 and CO measurements in the sample are difficult, because of tars and hydrocarbon condensation. Recommends trying a charcoal filter. Composition of volatile organic compounds. Method is to use EPA method TO-14 from the Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, EPA 600/4-84-041, May 1988.	GC available 2% of measurement accuracy	

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c5:** ***Microgravity Smoldering Combustion (MSC)***	**FCF Capabilities**	**Compliance Comments**
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity			
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity			
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles			

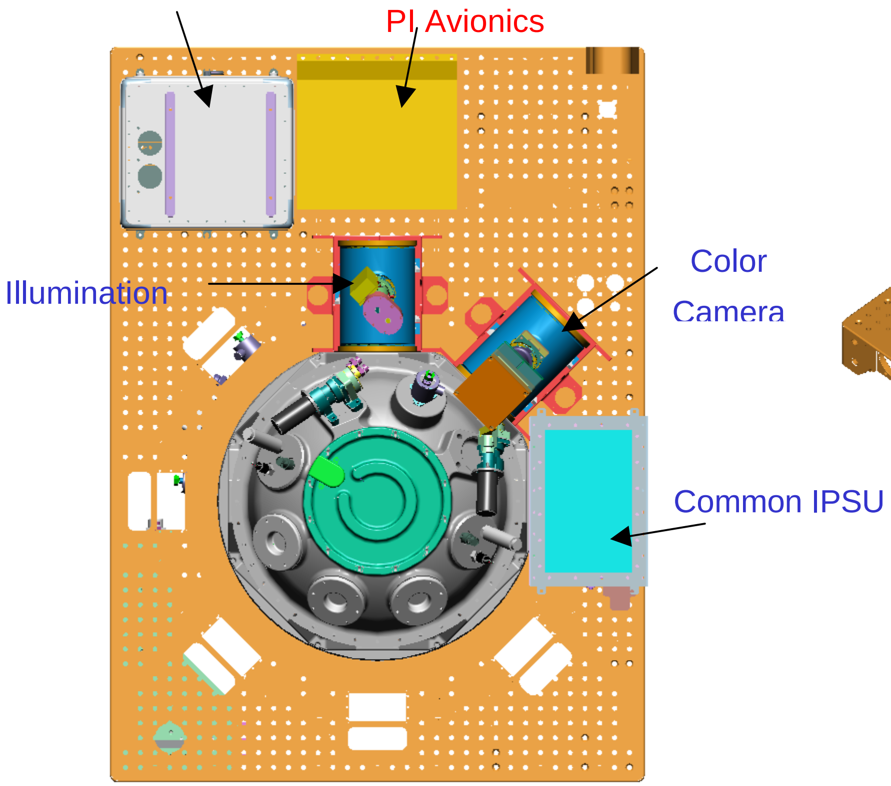
Requirement Type: ***Experiment Measurements***	SRD Requirements for c5: ***Microgravity Smoldering Combustion (MSC)***	FCF Capabilities	Compliance Comments
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles			
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate	Desired to be measured to within 2%. SAMS data if available.	SAMS data available	
Other Experiment Measurements	Ultrasound Imaging: To determine the passage of the smolder reaction and char permeability. 5 stationary locations along the axis of the cylindrical foam sample. Speaker and transmitter pairs to be at 40 +/- 0.5 kHz. (Additional requirements in the SRD.) One scan every 10 sec desired.	PI-provided H/W	[PI hardware]

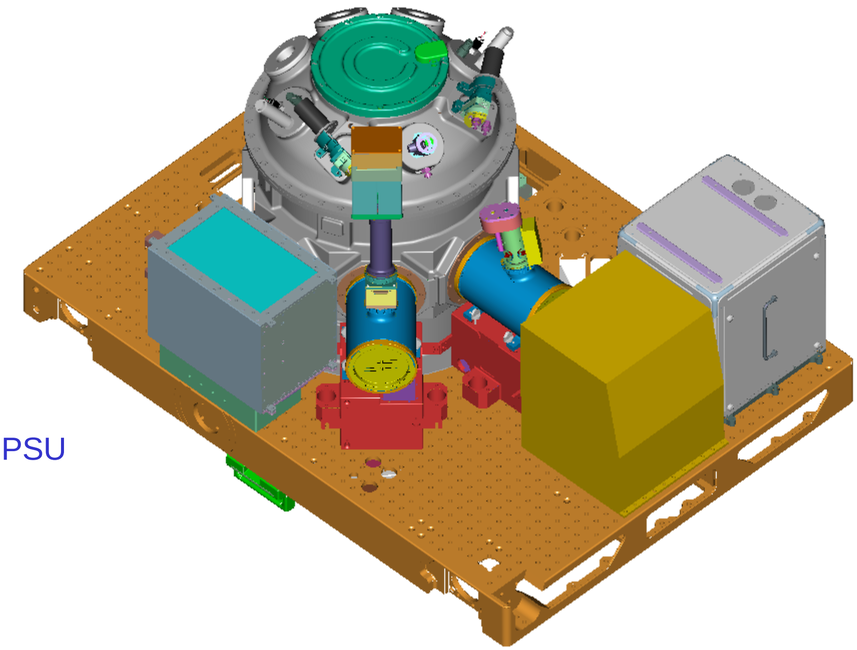
Requirement Type: ***Data Management***	**SRD Requirements for c5:** ***Microgravity Smoldering Combustion (MSC)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	Video images to include time stamp in seconds. All data streams to be time correlated.	Video imaging will be time stamped and data streams correlated.	
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.			
Other Data Management			

Requirement Type: ***Operations***	**SRD Requirements for c5:** ***Microgravity Smoldering Combustion (MSC)***	**FCF Capabilities**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing			
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)			
Auxiliary data Primary environmental parameters ISS data			
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points			
Crew operations Crew observations during sample exchange Crew observ. during test runs Other			

Requirement Type: ***Operations***	**SRD Requirements for c5:** ***Microgravity Smoldering Combustion (MSC)***	**FCF Capabilities**	**Compliance Comments**
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points	Turn on ignitor. Set ignition flow. Record temperatures and images. Turn off ignitor after a set period of time. Set flow to test condition. Turn off experiment power if all thermocouples give temperatures below 150 C. Extinction has occurred. Turn of ignitor if any thermocouples give temperatures above 1000 C (flaming condition), but record experiment to completion.	Test point sequencing to be performed by ground command.	
Post-flight sample and hardware return			
Other Operations			

Proposed diagnostics layout





Science Requirements Document Summary for

Droplet Combustion Experiment Reflight (DCE II) (c6)

SRD Date: November 19, 1998, August 1994

Principal Investigator: Prof. Forman Williams, University of California, San Diego

Project Scientist: Dr. Vedha Nayagam

Project Manager: John Haggard

Experiment Objective:

The general purpose is to produce benchmark experimental data over a wide range of initial conditions that will provide a basis for understanding droplet burning and extinction processes. A wide range of droplet sizes over a range of ambient environments will be studied. The experimental data will be utilized to test theoretical predictions of liquid-phase and gas-phase steady and unsteady phenomena and to test theoretical prediction of extinction phenomena.

Experiment Summary:

An isolated fuel droplet ranging in size from 1 to 5 mm is grown, deployed, and ignited in a quiescent environment of oxygen/helium or oxygen/nitrogen. The fuel may be one component, or have water added. The initial pressure ranges from 0.5 to 3 atm; the oxygen concentration ranges from 0.13 to 0.50. The flame and droplet images are obtained.

Requirement Type: *Experiment Operating Conditions*	SRD Requirements for c6: *Droplet Combustion Experiment Reflight (DCE II)*	FCF Capabilities	Compliance Comments
Test Section Dimensions Volume Dimensions Shape	Minimum free volume is 30 L. Spherical zone of 20 initial droplet diameters around the deployment site.	CIR chamber provides 100L of free volume	[DCE PI insert]
Fuel State Physical state of fuel Storage Distribution Mixing Handling	Liquid fuels of 99.8% purity. N-heptane, methanol, methanol/water mixes ranging from 5 to 15% water. Initial droplet size range is 1.5 to 6 +/- 0.25 mm, rep to 5, max velocity is 0.3 to 6 mm/s or greater. Some droplets on tethers. Droplet deformation minimized.	Fuel PI-provided Formation of droplet part of the CIA PI-provided H/W	[Cartridges on DCE PI insert. Chamber access to replenish fuel cartridges]. *SRED max. droplet dia. is 5mm*
Ignition Igniter Power Control Geometry	Hot wire using minimum energy without imparting momentum or excessively heating the droplet. Location variable from 1-2 to 5 droplet radii.	Part of the PI-provided H/W (CIA)	[On DCE PI insert]
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	Quasi-steady is 0.6-60x10^{-5} g/g_o. Longer burning (usually larger) droplets required lower g levels.	Rack Isolation System will be operational (ARIS)	
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	Initial pressure 0.25 to 3.0 +/- 0.05 atm. Maximum pressure rise is 10% of initial pressure.	Within the CIR chamber design pressures	

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c6:** ***Droplet Combustion Experiment Reflight (DCE II)***	**FCF Capabilities**	**Compliance Comments**
Operating Temperature Gas temperature control Condensed phase fuel temperature control	18 to 27 degrees C.	CIR complies	[DCE considering using water loop on insert to minimize temperature rise seen on MSL-1].
Oxidizer Composition Components Range Accuracy	Oxygen/nitrogen with 0.20 to 0.40 oxygen mole fraction. Oxygen/nitrogen/helium with 0.20 to 0.30 oxygen mole fraction and 0.02 to 0.25 helium mole fraction. Initial oxygen mole fraction accurate to +/- 0.005; if used for multiple burns than +/- 0.01 for subsequent tests. Highly desirable to perform gas sampling during multiple droplet burns to verify the oxygen concentration. Initial water vapor <2% RH for methanol. Initial trace contaminants individually less than 0.02. Fuel vapor mole fraction less than 0.005.	CIR FOMA complies. The O2/N2 environment can be delivered by combinations of any of the three oxidant bottles: 1L 85%O2, 2.25L 50%O2 or 3.8L30%O2. ISS N2 will be used to dilute the proper mixture. He is provided in one or two of the bottle sizes specified above depending on the number of O2 needed.	[FOMA-provided]. *SRED Fig. C5a indicates O2 from 5-20%. SRED App. B indicates O2 from 10-50%.*
Fuel Flow Flow rate Range Duration Accuracy Stability	N/A		
Oxidizer Flow Flow rate Range Duration Accuracy Stability	Combustion must occur in a quiescent chamber. A waiting time of 1 to 20 minutes is required after chamber fill, mixing, or purging.	Requirement is achievable	

Requirement Type: ***Experiment Operating Conditions***	**SRD Requirements for c6:** ***Droplet Combustion Experiment Reflight (DCE II)***	**FCF Capabilities**	**Compliance Comments**
Number, duration of tests	3 sets of 100 runs each, ranging in time from 5 to 20 s of burn time.	Total burn time supported depending on cameras runtime (see below: Experiment Measurements)	[Exact test points to be specified after ground-based testing]. *SRED App. B and Fig. C7 indicate 70 test points.*
Other Experiment Conditions			

Requirement Type: *Experiment Measurements*	SRD Requirements for c6: *Droplet Combustion Experiment Reflight (DCE II)*	FCF Capabilities	Compliance Comments
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	Primary Imager - Droplet Imaging: Droplet diameter from 6 mm to 200 microns. 80 frames per s. 3.3 cm field of view or larger. 18 microns resolution (to measure droplet diameter to 10%) 3 cm depth of field. Used with back light illumination. During combustion and post-extinction evaporation. If digital technology cannot meet FOV and resolution requirements, then requirements are relaxed: • Droplet Initial Dia. 3mm to 6 mm: Instantaneous FOV 30 x 30 mm, resolution 60 microns. • Droplet Initial Dia. 2 mm to 3 mm: Instantaneous FOV 20 x 20 mm, resolution 40 microns. • Droplet Initial Dia. 1 mm to 2 mm: Instantaneous FOV 10 x 10 mm, resolution 20 microns. Tracking velocity at least 10 mm/sec. Total tracking FOV 50 mm x 50 mm.	HFR/HR package operating at 110 fps; 48mm dia. total FOV w/ 10mm sq. Instantaneous FOV; 83 µm resolution or 50µm when operating in the HR mode (30fps) Depth of field provided by means of autofocus over 30mm range. Currently 9.2mm/s tracking ability over a 48mm dia field Telecentric optics Backlight provided with Illumination Package 50 mm dia total FOV provided with HiBMs package; resolution is 180µm; 30 fps. Telecentric optics. Supplemental backlight must be provided by PI.	Instantaneous FOV requirement not in SRED *Tracking requirements not in SRED*

Requirement Type: *Experiment Measurements*	SRD Requirements for c6: *Droplet Combustion Experiment Reflight (DCE II)*	FCF Capabilities	Compliance Comments
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	Secondary Imager: Image of droplet dispensing, deployment, ignition, and freely floating position, to be used for real-time decision-making on droplet deployment and ignition parameters. 30 frames per s. 4 cm. field of view	Color camera provided. 30 fps 35 to 5.8 cm square FOV	
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	CH* imager: 30 frames per second. Field of view 6 cm centered about the deployment site. Resolution standard video. Depth of field 4 cm centered at the deployment site. Low light level image of CH radicals at 431 +/- 5 nm, with a bandpass of 10 nm FWHM. Time stamped. Collinear with the OH* view. Not necessary to be orthogonal to droplet view. Gain settings to avoid saturation and cover broad dynamic range, adjustable in flight.	LLL near IR camera package; 400-900 nm spectral range at 10% of peak sensitivity. 10nm FWHM @ 431nm 212 to 42 mm sq. FOV Depth of field depending on FOV and aperture setting. Depth is 3.5 mm @60mm FOV and full aperture; 120µm resolution at full aperture and 60mm FOV. 30 fps. Time stamped. Can be placed collinear with OH view. Auto gain available. Gain setting can be uplinked	*Not required by SRED*

Requirement Type: *Experiment Measurements*	SRD Requirements for c6: *Droplet Combustion Experiment Reflight (DCE II)*	FCF Capabilities	Compliance Comments
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	N/A		
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	Flame Imaging: Oriented orthogonal to the droplet position. 30 frames per s. 4 cm field of view centered at droplet deployment site. 90 microns resolution. Able to detect dim droplet flames. Must be able to adjust camera gain in flight. 310 nm with a 10 nm FWHM. During combustion.	LLL UV imager provided Can be positioned orthogonal to droplet imager and collinear with CH imager. 30 fps Same features as CH camera 280-700 nm spectral range at 50% of peak sensitivity; 83 μm resolution @ 40mm FOV and full aperture; 1.8mm depth of field @ 42mm FOV and full aperture. 10nm FWHM @ 310nm filter.	SRED shows 3.5cm.

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c6:** ***Droplet Combustion Experiment Reflight (DCE II)***	**FCF Capabilities**	**Compliance Comments**
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate	Chamber environment. Sampling rate of 10 Hz. Precision of 1 C. Range is near ambient. If fuel is stored outside the chamber, a separate measurement is required.	CIR complies	
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate	N/A		
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	Test chamber pressure from before fuel dispensing through combustion and post-combustion vaporization process. 10 Hz sampling rate. 0.25 to 3 atm. 0.01 atm resolution.	CIR complies	
Chemical composition Species Range Accuracy	Oxygen concentration using post-combustion gas sampling.	GC provided	

Requirement Type: ***Experiment Measurements***	**SRD Requirements for c6:** ***Droplet Combustion Experiment Reflight (DCE II)***	**FCF Capabilities**	**Compliance Comments**
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity	N/A		
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity	1 (2 desired) radiometer with wide band 1 to 5 microns. 1 (2 desired) radiometer with 1.87 micron H_2O filter. Accuracy 5% of full scale reading over the range 0-TBD W/cm2. Response time constant < 40 ms. Located at least 10 flame radii from droplet. See the entire flame throughout the burning history. Shield from ignitor wires. Sample at 10 Hz (30 Hz desired). Time synchronized with other data and stamped with GMT. Sample just prior to ignition through a few seconds past flame extinction.	PI-provided H/W. Radiometers can be part of CIA or located at available UMLs outside the chamber. Window with appropriate transmission is provided. Sampling rate controlled by PI electronic enclosure via IRR	[DCE to provide radiometers and filters].
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles	N/A		

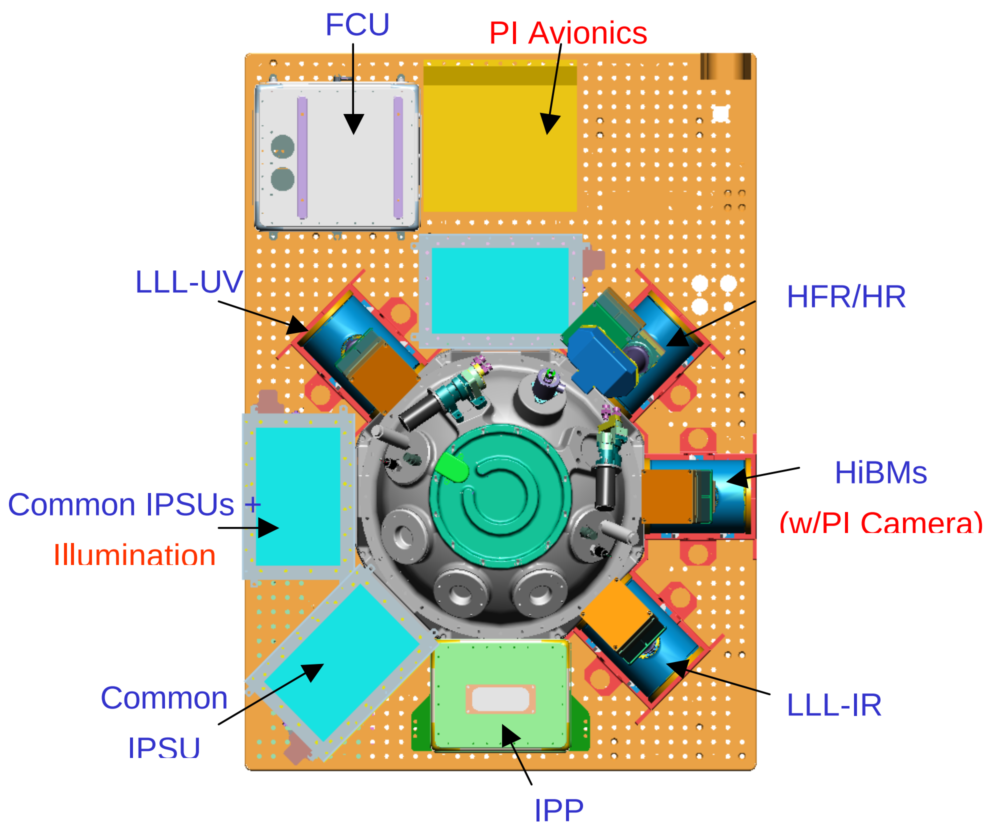
Requirement Type: *Experiment Measurements*	SRD Requirements for c6: *Droplet Combustion Experiment Reflight (DCE II)*	FCF Capabilities	Compliance Comments
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles	N/A		
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate	3 axes Precision of $1x10^{-6}$ g_o 0.01 to 125 Hz.		
Other Experiment Measurements			

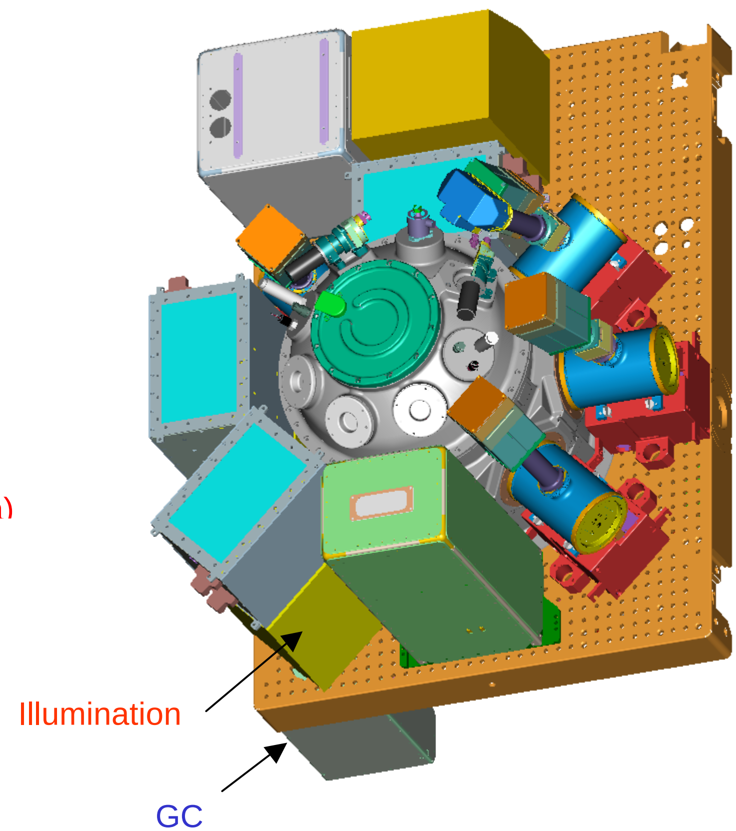
Requirement Type: ***Data Management***	**SRD Requirements for c6:** ***Droplet Combustion Experiment Reflight (DCE II)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	Droplet and flame images must be synchronized within 0.03 s, referenced with +/- 0.03 s of GMT. Secondary imager desired to be referenced to GMT to +/- 0.03 s. Acceleration measurements must be synchronized with the cameras.	CIR Complies All data is time referenced with at least 10ms accuracy Acceleration measurement synchronization is TBD	*Requirement not in SRED*
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.	4 Field: Backlit droplet view, OH*, CH*, secondary color imager 7 Single sensor: Temperature, pressure, 4 radiometer, oxygen	CIR complies if radiometers are placed inside chamber	
Other Data Management			

Requirement Type: ***Operations***	**SRD Requirements for c6:** ***Droplet Combustion Experiment Reflight (DCE II)***	**FCF Capabilities**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing			
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)			
Auxiliary data Primary environmental parameters ISS data			
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points	Near-real time data downlink: Secondary imager required, flame and droplet imagers desired. Parameters requiring control: flame imagers (OH* and CH*) gain.	Data downlink depending on ISS resources All data and parameters settings can be downlinked	

Requirement Type: ***Operations***	**SRD Requirements for c6:** ***Droplet Combustion Experiment Reflight (DCE II)***	**FCF Capabilities**	**Compliance Comments**
Crew operations Crew observations during sample exchange Crew observations during test runs Other			
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points			
Post-flight sample and hardware return			
Other Operations			

Proposed diagnostics layouts





Science Requirements Document Summary for

Laminar Soot Processes (LSP) (c7)

SRD Date: May 1994, September 10, 1998 (Requirements from the LSP Verification Matrix)

Principal Investigator: Prof. G. M. Faeth

Project Scientist: Dr. David L. Urban

Project Manager: Ms. Ann P. Over

Experiment Objective:

To obtain a better understanding of soot formation, oxidation and radiative properties within nonpremixed flames. These properties are important because they affect the performance of propulsion systems, the hazards of unwanted fires, and the pollutant emissions from combustion processes.

Experiment Summary:

A small round jet diffusion flame is established in an oxidizing environment. Soot volume fraction, soot temperature, flame radiation, flame shape and size, soot morphology, and flame smoke heights are measured.

Requirement Types: *Experiment Operating Conditions*	SRD Requirements for c7: *Laminar Soot Processes (LSP)*	FCF Capabilities	Compliance Comments
Test Section Dimensions Volume Dimensions Shape	**Chamber**: The volume shall be sufficient to assure that no more than 10% oxygen will be consumed during a test. The emissivity of wall surface and hardware internal to the chamber, where possible, shall be 0.8 or better in the visible range (.4 nm to .75 nm). This applies to the components in view of the cameras, radiometer and flames. **Chamber Viewports**: Two required. Window #1: Capable of passing visible light and observing luminous flames 80 mm x 15-25 mm. Window #2: Capable of passing infrared (1000-5000 nm) observing same region with a wider wavelength preferred. Provision to exclude light from entering the chamber is required to minimize optical background. Light shall be provided to illuminate inside of chamber before the test. Except for the burner tube and the soot sampling probes (briefly) there will be no intrusion of the experimental hardware to within a 48 mm cylindrical radius about the flame axis extending from the tip of the burner to the temperature measuring stations, and a 48 mm radius hemisphere extending below the tip of the burner.	CIR chamber free volume is 100L No wall emissivity requirement in SRED. CIR complies w/window size and transmission characteristics Stray light blocking provided Chamber illumination must be provided by PI. Burner and soot sampler is PI-provided (CIA)	*SRED for c7 does not show spectral requirements in near-IR*

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Fuel State Physical state of fuel Storage Distribution Mixing Handling	**Fuels** are ethylene and propane. Acceptable impurity levels at the bottles can be twice that of best available gas. Provide fuel for test matrix plus contingency for ±30% adjustment in parameters. [4.5] **Fuel Nozzle Exit diameter**: Required range of burner tube inside diameters is 0.4 to 1.6 mm with a maximum exit wall thickness of 0.25 mm. [4.A and 4.1] **Fuel Nozzle Location**: Fixed along the axis of the test chamber and aligned with instrumentation to generate a round jet diffusion flame along axis of test chamber. The axis of the nozzle and the axis of the instrumentation shall be within ±1 mm of the axis of the test chamber. [4.A] VER[3.2.6.2b] **Fuel Nozzle shape**: 30 degree outside taper with exit wall thickness no greater than .25 mm. [4.1] **Flow conditioning**: Flow condition at nozzle exit must be fully developed laminar flow with negligible swirl. [4.A] The burner tip should be positioned so that at least 10 mm of the burner tube and the maximum full visible length (80mm) and width (25mm) of the flames be visible through windows in the chamber walls. **Fuel Nozzle material**: Burner material shall be stainless steel [4.A]	Fuels are PI-provided in CIR standard bottle sizes (1L, 2.25L and/or 3.8L) Fuel nozzle is part of the PI H/W (CIA). Flow conditioning and burner location part of CIA design	*SRED App. B indicates other fuels as acetylene/n2 and propylene/n2.*
Ignition Igniter Power Control Geometry	**Ignite fuel** by hot wire coil or continuous spark. [4.A] **Igniter Location**: Near jet exit but outside flame sheet. [4.A] **Igniter Operations**: Deactivate igniter following ignition. Capability to move away from nozzle desire. [4.A and 4.1]	Igniter is PI H/W (CIA)	

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	A peak acceleration level of less than 10-3 over the duration of the combustion test required.	CIR will operate with ARIS	
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	**Pressure Requirement**. Tests will be performed at 0.5 to 1.0 atm. Accuracy = ±5% of reading. [4.B and 4.1] Chamber Pressure Fill Accuracy: ±5% of reading. [4.B]	Requirement is within CIR chamber operating specifications.	
Operating Temperature Gas temperature control Condensed phase fuel temperature control	**Fuel Initial temperature**: 280-320K. [4.A] **Oxidizer Initial temperature**: 280 to 320K. [4.A]	Fuel temperature within range for compliance.	
Oxidizer Composition Components Range Accuracy	**Oxidizer**: Commercial grade dry air (dewpoint less than 273K at start of combustion). Oxygen/nitrogen mixture (21 mole % ±1 mole % oxygen in nitrogen). [4.A] **Oxidizer consumption**: A maximum of 10% of the ambient oxygen shall be consumed at any test condition. [4.A] **Oxidizer**: Provide oxidizer for test matrix. [4.4]	The O2/N2 environment can be delivered by combinations of any of the 3 oxidant bottles; 1L 85%O2, 2.25L 50%O2 or 3.8L 30%O2 (all with balanced N2). ISS N2 will be used to dilute the proper mixture.	
Fuel Flow Flow rate Range Duration Accuracy Stability	**Fuel mass flow rates**: 0.70 - 1.92 mg/s. Set point accuracy: ±10% of reading. Stability ±5% throughout the burn time. [4.B] The fuel flow rate shall be adjustable during the Flame Development Period to within ±5% of the current value.	The fuel flow rate is within the FOMA mass flow controller capability on fuel/premixed fuel supply manifold.	*SRED App. B indicates .4-2 mg/s. SRED Fig. C6 indicates 5 cc/sec.*

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Oxidizer Flow Flow rate Range Duration Accuracy Stability	NA		
Number, duration of tests	**Number of tests**: 14. An additional desired prioritized matrix presented for use if opportunity presents itself. [4.4.2 Table 4] Flame development times: a) required 15 and 30 s at 0.5 and 1.0 atm. b) desired 30 and 60 s at 0.5 and 1.0 atm. Test flame duration up to 255 sec. [4.A.6]	Bottle and venting combinations can be determined for the desired number of tests points. *Duration within bottle sizes.*	*SRED Fig. C7 indicates duration between 350-600 sec.*
Other Experiment Conditions			

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	**Flame Imaging**: One color view in the visible wavelength region. Another at 90 degrees is desired (can be of lower resolution). [4.B] **Frame-rate**: 1 fps [4.B] **Field of view**: Area centered on flame axis 60 mm wide; 80 mm long. [4.A and 4.B] Burner tube tip shall be visible on video records of flame shape. [4.A] **Spatial resolution**: 750 µm [4.B] **Depth of field**: 25 mm [4.B] Provide capability to distinguish the blue and yellow (soot containing) portion of the flame.	One color imager provided; 30 fps or less; 58-350mm sq. FOV; 312µm resolution at 80mm FOV. 4mm DOF at 80mm FOV and full aperture; autofocus available; 2 lux sensitivity. As a second imager, the near-IR LLL package is available. B/W; covers 500-875nm spectral bad; 30 fps or less; 42 to 212mm sq. FOV; 156µm resolution and 7mm DOF at 80mm FOV; autofocus is available.	
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	NA		

Requirement Types: ***Experiment Measurements***	SRD Requirements for c7: ***Laminar Soot Processes (LSP)***	FCF Capabilities	Compliance Comments
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	NA		
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate	Chamber Gas Temperature Environment: Number of measurements: 2 [4.B]. Location: near side walls. [4.B]. Range: 280-320 K ambient gas near wall. [4.A]. Accuracy: ±3 K [4.B]. Sample rate: 1 measurement per second. [4.2] **Fuel Temperature**: Number of measurements: One [4.1.5. Location: Before flow conditioner. [4.1.5]. Range: 280-320K. [4.A]. Accuracy: ±3K. [4.B]. Sample rate: 1 measurement per second. [4.B. **Flame Temperature Distribution**: Number of rakes: One [4.B]. PI suggested configuration: Maximum thermocouple bead diameter: 130 microns (= .005 in.) Bead is 10 to 20 wire diameters from the sheath. [4.B and 4.2.3]. No of elements: 5 are required; 10 are preferred. TCs are symmetrically placed across the radius of the flow (60 mm) so that asymmetries of the flow can be quantified. [4.B]. Location: 150-200 mm from nozzle tip, centered along a radius in the fuel-lean portion of the flame, beyond the soot containing region. [4.B]. Range: Less than 1000K. [4.B]. Spatial resolution: radial: ±1 mm, streamwise: ±3 mm. Position accuracy is 3 mm any direction. [4.B]. Sample rate: 1 profile every 10 seconds. [4.B].	CIR provides chamber temperature measurements at 4 locations: 2 in rear end cap and 2 in the IRR are at least 1 Hz rate. Wall (window section) temperature measurements is PI-provided. (PI H/W in CIA, electrical interfaces provided in IRR). Fuel Temperature is PI-provided (CIA). Flame Temperature distribution is PI-provided (CIA).	

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate	NA		
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	**Chamber Pressure**: Number of measurements: One [4.B] **Location**: Designer Select [4.B] **Range**: 0.5 to 1.0 atm. Variable ±30%. Accuracy ±10% of reading. [4.B] **Sample rate**: 1 Hz. [4.B and 4.2]	Chamber pressure measurements: 2 in IRR and 2 in rear end cap. CIR complies with range, accuracy and sampling rate.	
Chemical composition Species Range Accuracy	NA		

Requirement Types: *Experiment Measurements*	SRD Requirements for c7: *Laminar Soot Processes (LSP)*	FCF Capabilities	Compliance Comments
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity	**Soot Volume Fraction**: Non-intrusive, one pass laser extinction technique. 30-40 paths in the radial position across 20 mm soot containing region at each streamwise station. [4.C and 4.3.3]. Number of axial stations: full field of view (preferred), 6-7 stations over length of soot containing region (acceptable). [4.C]. Field of View: 30 mm radial (desired), 20 mm radial (required), 80 mm streamwise. Resolution: 1 mm radial, 3 mm streamwise. Wavelength: 600-900 nm [4.C]. Location: Laser source and detectors outside of chamber. [4.C]. Utilize the full dynamic range of the 8 bit digital data recording system. At least 480 x 480 pixel resolution. [4.3]. Up to 50% variation of the laser source strength over the FOV is acceptable. Spatial filtering to accept laser radiation directed within 0.5 of the optical axis preferred. Angular aperture of detector less than 6 , measured from mid-plane of flame. Out of the total FOV, not more than 10% should exhibit optical noise having intensity variations greater than 10% of the detector dynamic range. Baseline measurements with no flame present are required over the range of conditions to be considered before and after operations of the flame, to allow corrections of background and instrument effects, and to indicate any changes over the measuring period.	Illumination and imaging package for SVF are available: Use HiBMs for imaging. 80mm dia. FOV; telecentric optics; 200µm resolution (400 streamwise paths and 100 radial paths); 10nm bandpass FWHM; 12 bit depth; FOV is 796 pixels diameter; Numerical aperture 0.009; 15fps for 20 min. at full resolution and 12 bit depth; approx. 0.5 measurement cycles per sec expected when shared for soot temperature measurement depending on exposure parameters selected by PI. Illumination wavelength 675nm Uniformity better than 50%.	Requirements not shown in SRED.

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
	Soot Temperature: Provide a non-intrusive pyrometry system, with three wavelengths preferred, two required, deconvoluting results for cord-like paths. [4.C and 4.3.4]. Utilize the full dynamic range of the 8 bit digital data recording system. Wavelength: Lines within range of 550-900 nm, not coinciding with laser extinction; [4.C] Suggested lines near 632.8 and 900 nm. Temperature range: Greater than 800 - 1100 K. Number of chord-like paths: Full field of view (preferred); 30-40 radial positions across 20 mm soot-containing region at each streamwise station (acceptable). [4.C]. Field of View: 30 mm radial (desired), 20 mm radial (required), 80 mm streamwise. Resolution 0.5 mm. Collection f/# greater than (1 cm x # Active pixels (vertical))/(8 cm). Spatial Resolution: Radial: 1 mm Streamwise: 3 mm. Soot Temp signal level adjustment technique such as camera shuttering to utilize the full dynamic range of the camera output. [Rev. B section 2-5].	CIR provides HiBMs package. Tunable filter covers 650 to 1050nm with 1 nm resolution and 10 nm bandpass at FWHM; wavelength choice is software controllable, approx. 100ms required for wavelength state change; Sensitivity is 1200 to 2000K; NA adjustable from 0.006 to 0.019; Autoexposure is available controlling gain, iris or shutter speed.	Wavelengths are not specified in SRED. Temperature range is not a SRED requirement *Collection f/# not specified in SRED*

Requirement Types: *Experiment Measurements*	SRD Requirements for c7: *Laminar Soot Processes (LSP)*	FCF Capabilities	Compliance Comments
	Soot Sampling Techniques: Thermophoretic system sampling on TEM grids. [4.C]. Number of locations: 2 required, 4 preferred. First probe center line shall be 15 mm from the nozzle exit. Other probe center lines evenly spaced with center lines within 15 and 80 mm from the nozzle exit. [4.C and 4.3.3]. Sample area size: center line of TEM grid nearest nozzle shall be capable of going to center line of the nozzle. The probe width shall be no more than 5 mm. Grids shall cover half the width of the flame (10 mm). [4.c]. When retracted, soot sampler components shall be no less than 48 mm from the flame axis. Flame disturbance by probe movement shall be reduced as much as practical. [4.C]. The transient time to insert and retract the grids shall be no greater than 50 ms each way with a sampling period from between 200 - 550 ms. [4.C and 4.3.3]. Allow 10 sec. for sampling disturbances to decay before undertaking any measurements beyond the sample position. [4.C]. Probes to be capable of being inserted one at a time with the first probe being the one furthest from the nozzle. [4.C and 4.3.3]. The center line of the first grid on each sample probe shall be within a 1 mm cylindrical radius centered on the nozzle axis. [4.C]. TEM grid: 200 mesh copper grids supported by 200 angstroms thick elemental carbon film. The chamber environment shall not contaminate the grids. [4.C and 4.3.3]. Control induced vibration of the nozzle and soot sample probes such that the centerline of the first grid on each sample shall remain inside a 1 mm radius cylinder centered on the flame axis. [4.C]	Soot sampling is PI H/W in CIA controlled by PI electronic enclosure via chamber IRR	

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity	**Flame Radiation**: One location [4.A] **Wavelength Range**: 1000-5000 nm or wider. [4.B] **Sample Rate**: One per second [4.B] **Field of View**: At least 60 mm wide by 80 mm long starting at nozzle tip. Must have unobstructed view of flame. [4.B and 4.2.4] **Accuracy**: ±5% of full scale reading over the range 0 to 220 mW/cm2. [4.B]	PI-provided H/W (CIA)	
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles	NA		
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles	NA		

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate	Record to 10-4 g on 3 axis. [4.B] **Sampling rate**: 50 sps per axis during the experiment. Accuracy ±10% of reading. [4.B]	SAMS triaxial sensor provided.	
Other Experiment Measurements	**Fuel Flow Rate**: Number of Measurements: One. Measurement Location - Designer Choice. Estimated measurement Range: 0.4 to 2 mg/s. Measurement Accuracy: ±5% of reading. Measurement Sample Rate: 1 Hz.	The flow rate in SLM for fuel is within the capability of the 2SLM Mass Flow Controller on the Fuel/Premixed Fuel Supply Manifold.	

Requirement Types: ***Data Management***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	Except for soot sampling, data should be taken throughout both flame development and steady-state times. Science data and video data should be correlated to 0.1 sec [4.1]	Adequate data storage is available for support of test durations of at least 15 min. Better than 0.1sec. time correlation is provided	
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.	**Field**: 4-6: Color flame image (1-2), soot volume fraction image, soot temperature measurement images (2-3). **Single sensor**: 10-15: Pressure, Gas temperature (2), Fuel temperature, flame temperature (5-10), radiometer Fuel mass flow rate.	Soot volume fraction and soot temperature images are not available simultaneously.	*Not an SRED requirement*
Other Data Management			

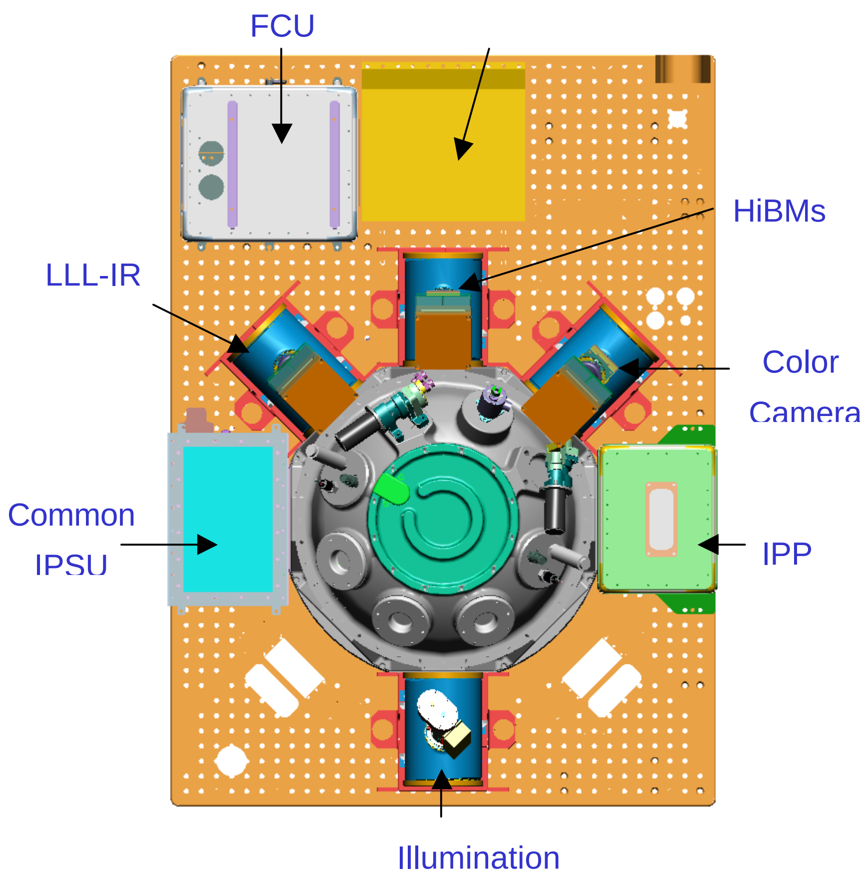
Requirement Types: ***Operations***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing	**Experiment Preparations**: Communications, data acquisition and control system operation should be verified using a standard test program. Laser, detector (laser extinction, radiometer, bi-chrometer), soot sampling system, and ignition system operation should be verified. Baseline traverses of the laser extinction and soot temperature systems should be completed. The flame image should be checked and image recording operation verified. The fuel supply shut-off valve should be opened. [3.4.1]	Simulators of FCF systems will be provided to allow the PI and their development teams to conduct testing to verify that the FCF will meet their science requirements. The Ground Integration Unit will be used for final interface verification testing which will verify that the ground operators can communicate with the science hardware in addition to verification of FCF/PI hardware compatibility. The capability to conduct sample test points in the GIU is TBD.	Mission sequence testing is not currently envisioned.
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)		The CIR will periodically recalibrate all sensors and diagnostics.	

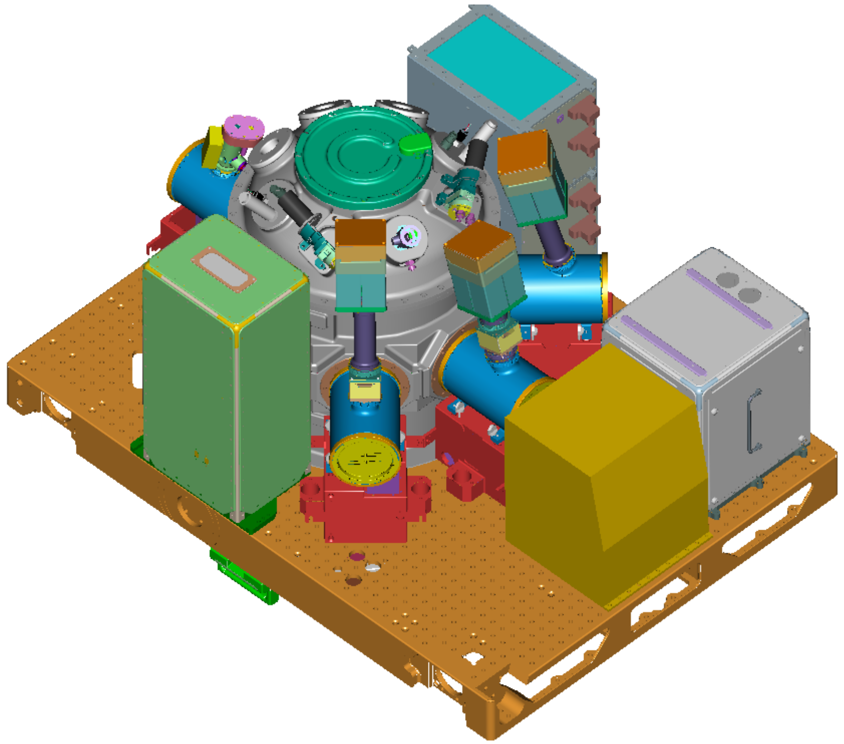
Requirement Types: ***Operations***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Auxiliary data Primary environmental parameters ISS data		The FCF will downlink all required parameters. These will be defined in the FCF to PI ICD and Integration Agreement. ISS parameters will be available through user defined packets at the operations site.	
Telescience **Near-real-time data downlink** Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points	**Downlink Requirements**: Provide capability to downlink the following data: digitized video frames, analog video, radiometer, thermocouple, chamber environment, housekeeping data, and uplink data. [3.3.6] **Flame Imaging**: Imaging data downlinked in near "real time" for analysis prior to initiating next test (includes color video, housekeeping data and a few frames of digitized data). [4.5.4] **Uplink Requirements**: Provide capability to up link the following commands and test matrix changes: fuel flow rates, ignitor power levels, data accumulation times, number of data records, soot sampler residence times, signal levels for transducers and ignite, reignite, respark and reburn commands. [3.3.7] Possible in-flight modifications of the test matrix include changes of fuel flow rates, ignitor power levels, accumulation periods of data once flames have become steady, soot sampler residence times, and the signal levels of radiometer temperature distribution, laser extinction and soot temperature (if provided) measurements. [3.4.5] It is required that each of these variables be capable of adjustments of ±30% from pre-flight optimized values using flight hardware. [3.4.5]	All sensor data (radiometer, thermocouple, chamber environment, housekeeping data) as well as analog video will be downlinked during operations subject to AOS/LOS restrictions. The FCF will record all data for later downlink as needed. The FCF will record all digital imagery data for downlink as bandwidth is available. Sufficient storage is provided to prevent any loss of data. The CIR will allow in-flight modifications of the test matrix.	

Requirement Types: ***Operations***	**SRD Requirements for c7:** ***Laminar Soot Processes (LSP)***	**FCF Capabilities**	**Compliance Comments**
Crew operations Crew observations during sample exchange Crew observations during test runs Other		During sample exchanges the ground operations staff will be monitoring the crew voice and will be in direct communication with the crew as required.	In general the crew will not be used to monitor test runs
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points	**Test Operations**: The operation of the experiment will be under computer control. The sequence of operations should be as follows: initiate operation of flame imaging and fuel flow, verify ignition (by experiment operator if possible), initiate soot property measurements after the appropriate flame development time, complete soot property measurements, turn off laser, terminate fuel flow-rate, and end imaging operation and data acquisition after 20-30/s delay to obtain final baseline values. [3.4.2] **Post Test Operations**: 1. Post test operations will vary depending upon whether the chamber must be vented and soot samples removed prior to the next test. If no venting and sample removal are required, setting the new fuel flow rate and adjusting the chamber pressure by adding air are the only operations that must be carried out before preceding with the next test. [3.4.3]. 2. If venting and sample removal are carried out, operating systems should be de-energized and the fuel supply valve should be closed. The chamber should be vented, backfilled with cabin air and opened. Components within the test chamber should be inspected for integrity and the soot samples removed the new sample grids installed if more tests are to be conducted.	ISS provides a scripting capability that provides this function. The CIR software architecture also provides computer control of experiment sequencing. CIR will comply with post test operations requirement 1.	

Requirement Types: *Operations*	SRD Requirements for c7: *Laminar Soot Processes (LSP)*	FCF Capabilities	Compliance Comments
	Test Frequency: 1. An interval of 2 hours should be provided between the first test point and subsequent test points to allow downlink of data, confirmation of hardware operation, evaluation of data. This requires downlink of video, engineering and science data, soot volume fraction and soot temperature (if available) data. [3.4.4]. 2. An interval of 1 hour should be provided between subsequent tests to assess the measurements. In this case, only downlink of engineering and science data, video, and a few digital frames of each cam era are required. [3.4.4]	Time between test points will be defined during the execution planning of the experiment. CIR will comply to the extent possible. In some cases it may be required to wait more that the required time due to AOS/LOS and bandwidth restrictions on downlink.	
34. Post-flight sample and hardware return	**TEM Sample handling**: Samples to be returned to earth for analysis. [4.C] VER[3.3.4.1j]	CIR will comply.	
Other Operations			

Proposed diagnostics layout





Science Requirements Document Summary for

Sooting and Radiative Effects in Droplet Combustion (SEDC) (c8)

SRD Date: September 27, 1996 and 1997 NRA proposal

Principal Investigator: Prof. Mun Y. Choi
Project Scientist: Dr. Paul Ferkul
Project Manager: Rodger Slutz

Experiment Objective:

To perform detailed quantitative measurements of the soot concentration distribution, temperature distribution, and soot morphology on single, isolated burning droplets. These experiments will measure the influence of soot on droplet burning rate, flame structure, and flame extinction.

Experiment Summary:

An isolated droplet is grown, deployed, and ignited in an environment of oxygen/nitrogen or oxygen/helium. The fuels and conditions are chosen so that sooting flames are produced. Measurements of droplet and flame diameter, soot volume fraction, soot temperature, and soot morphology.

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c8:** ***Sooting and Radiative Effects in Droplet Combustion (SEDC)***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions Volume Dimensions Shape	After droplet formation and ignition, all hardware except the fiber must be retracted within a 50 mm radius. Chamber size large enough to permit the oxygen concentration to change by no more than 1% and the allowable pressure rise is 0.01 atm during burning. Chamber walls and all internal components should have small reflectivity to minimize stray light interference with optics.	CIR chamber free volume is 100L Chamber will be black anodized	*Chamber walls finish requirement not in the SRED*
Fuel State Physical state of fuel Storage Distribution Mixing Handling	Fuels are n-heptane and ethanol. Purity 99.8% or higher. Fuel droplet size is 1.0 to 5.0 mm in diameter. Maximum allowed variation is less than 0.1 mm. Induced droplet drift velocity less than 1.5 mm/s. Droplet oscillations must decay prior to ignition to be less than 2% of the initial diameter. Times depend on initial diameter and are 3 s or less. Tethering of 4-5 mm droplets using thin silicon carbide fibers to constrain their movement.	Fuels are PI-provided. Droplet deployment apparatus must be part of the PI H/W (CIA)	
Ignition Igniter Power Control Geometry	Symmetric ignition using a minimum amount of energy. Ignitors placed 1.5 to 2.0 droplet diameters away from the center of the droplet. Temperature of 1500 K for 0.25 seconds. Position be varied for each experiment. Rate of retraction be approximately 15 mm/s. Ignitors as small as possible to minimize disturbances to the gas phase.	Ignition apparatus part of the PI H/W (CIA)	

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c8:** ***Sooting and Radiative Effects in Droplet Combustion (SEDC)***	**FCF Capabilities**	**Compliance Comments**
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	10^{-5} g_o	CIR will operate with an active ARIS	
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	Ambient pressure range is 0.25 to 2.0 atm +/- 0.05 atm.	CIR complies. Required range is within the chamber design specifications	*SRED App. B and Fig. C4a indicate 1 atm.*
Operating Temperature Gas temperature control Condensed phase fuel temperature control	Ambient temperature is 20 C. Range is 18 to 27 C.	CIR complies. ISS cabin temperature range	
Oxidizer Composition Components Range Accuracy	Oxygen/nitrogen mixtures, oxygen/helium, or oxygen/nitrogen/helium mixtures. Oxygen concentration range from 15 to 50% (molar basis). Measured to 0.01 mole fraction.	O2/diluent environments can be delivered by combinations of any of the three oxidant bottles; 1L 85%O2, 2.25L 50%O2 or 3.8L 30%O2 (all with balanced diluent). ISS N2 will be used to dilute the proper mixture when N2 is selected as diluent.	SRED App. B indicates additional diluents of argon and CO2. *SRED Fig. C5a indicates O2 to 40%.*
Fuel Flow Flow rate Range Duration Accuracy Stability	NA		

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c8:** ***Sooting and Radiative Effects in Droplet Combustion (SEDC)***	**FCF Capabilities**	**Compliance Comments**
Oxidizer Flow Flow rate Range Duration Accuracy Stability	NA		
Number, duration of tests	TBD tests. Half tethered. Only a few tests with helium.	TBD	*SRED Fig c7 indicates 70 test points.*
Other Experiment Conditions			

Requirement Types: *Experiment Measurements*	SRD Requirements for c8: *Sooting and Radiative Effects in Droplet Combustion (SEDC)*	FCF Capabilities	Compliance Comments
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	**Droplet imaging**: Droplet diameter measured with an accuracy of 1%. Temporal resolution of 0.01 s. Field of view must be sufficient to view largest droplets of 5 mm. **Color imager**: Color image of luminous flame zone. Field of view 50 mm. Resolution of 20 pixels/mm, 0.05 mm. Framing rate of 100 Hz.	Droplet diameter measurement accuracy depending on measurement algorithm selected by PI. PI is responsible for diameter measurement after receiving imaging data. CIR provides HFR/HR package operating in HFR mode. Droplet tracking will be operational for freely deployed droplets. Tracking algorithm can be turned off for tethered droplets. 10 mm FOV Temp. Res.= 0.01 s (110 fps) 83 µm resolution in HFR mode (package can also operate in HR mode: 30 fps; 50µm resolution). Package requires a backlight not provided by CIR if 2-wavelength pyrometry/soot volume fraction system is used. Color camera provided. 58mm sq. FOV; 2 lux sensitivity; field sequential at max. rate of 110 fps. 8.8 pixels/mm at 30 fps PI can provide optics to attach to camera for better resolution. Camera could provide up to 100 µm resolution with 50mm FOV optics at 10 fps.	Requirement for accuracy is not in SRED

Requirement Types: *Experiment Measurements*	SRD Requirements for c8: *Sooting and Radiative Effects in Droplet Combustion (SEDC)*	FCF Capabilities	Compliance Comments
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	NA		
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration		LLL UV Camera Package 310nm filter 10nm bandpass at FWHM; 212 to 42mm sq. FOV 30 fps Autoiris and autofocus 83 – 417 µm resolution at full aperture depending on zoom position. Time stamped. 20 min. run time Gain can be manual (by uplink) or automatic	[Proposal has OH emission imaging similar to DCE]. *SRED for c8 does not show this requirement.*

Requirement Types: *Experiment Measurements*	SRD Requirements for c8: *Sooting and Radiative Effects in Droplet Combustion (SEDC)*	FCF Capabilities	Compliance Comments
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate			*SRED shows requirement for c8 gas phase.*
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate	Two wavelength soot pyrometry. Range of 1000 to 2500 K. Accuracy of 50K. Field of view 50 mm. Spatial resolution 20 pixels/mm, 0.05 mm. Temporal resolution 100 Hz. Preferred wavelengths are 700 and 800 nm. Requirements are similar to LSP.	HiBMs package w/Liquid Filter tuned at 700 and 800 nm. 12bit digital output. Telecentric optics 80mm dia. FOV with 200µm resolution (50mm FOV could be provided by PI with approximately 94µm resolution). 15 fps at max. resolution; time stamping accuracy better than 0.01sec. (Camera can be operated at up to 30 fps in binning mode w/ 400µm resolution for 80mm FOV).	[Field of view should encompass total flame and soot area].
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	Pressure resolution 0.05 atm (0.001 atm in chart). Measured at 10 Hz.	CIR complies	

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c8:** ***Sooting and Radiative Effects in Droplet Combustion (SEDC)***	**FCF Capabilities**	**Compliance Comments**
Chemical composition Species Range Accuracy			

Requirement Types: *Experiment Measurements*	SRD Requirements for c8: *Sooting and Radiative Effects in Droplet Combustion (SEDC)*	FCF Capabilities	Compliance Comments
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity	**Soot volume fraction**: Required during the entire burning period. Uncertainty in the soot volume fraction be less than 10%. Laser and detector must provide stability of at least 5%. Detector must be linear. Laser must be sufficiently strong to provide 250 gray levels. Variation in laser intensity over the field of view should be less than 10%. Contributions from the luminous flame or stray emission must be minimized. Field of view 50 mm. Minimum droplet size to be measured is 0.1 mm and flame diameter of 0.5 mm. 10 data points are needed over this distance. Minimum magnification of 20 pixels/mm, 0.05 mm. Temporal resolution of 100 Hz. **Soot sampling**: Soot samples be taken using thermophoretic technique at t=0.05, 0.10, and 0.20 s and at 25%, 50%, 75%, and 90% of the time to extinction. Sampling to occur at different radial positions. One sample per droplet. Recommend for 5 mm droplet. Insertion and retraction time is 10 ms. Residence time is 50 ms.	HiBMs package w/Liquid Filter tuned at the illumination package laser wavelength (675nm) 12bit digital output (4096 gray levels). Telecentric 80mm dia. FOV with 200µm resolution (50mm FOV could be provided with approximately 94µm resolution) Max. frame-rate: 15 fps at max resolution. (Camera can be operated at up to 30 fps in binning mode w/ 400µm resolution for 80mm FOV); time stamping accuracy better than 10ms. Backlight provided via Illumination Package: uniformity better than 50% and stability better than 5% over the FOV. Laser output sufficient to reach detector saturation. Background substraction recommended during data reduction to eliminate non uniformities from the SVF computations. The package can be operated by cycling filter tuning and sequentially capture soot volume and soot temperature images. Filter needs 200ms for switching wavelengths. Soot Sampling is PI-provided.	[Preferred approach is full-field light extinction measurements] *Requirement not in SRED* [Field of view should encompass total flame and soot area]. *SRED min. droplet size is 0.18mm.* This min. droplet size combined with the accuracy requirement of 1% leads to a required resolution of 1µm. *This is outside the SRED requirement for resolution .*

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c8:** ***Sooting and Radiative Effects in Droplet Combustion (SEDC)***	**FCF Capabilities**	**Compliance Comments**
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity			
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles			
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles			

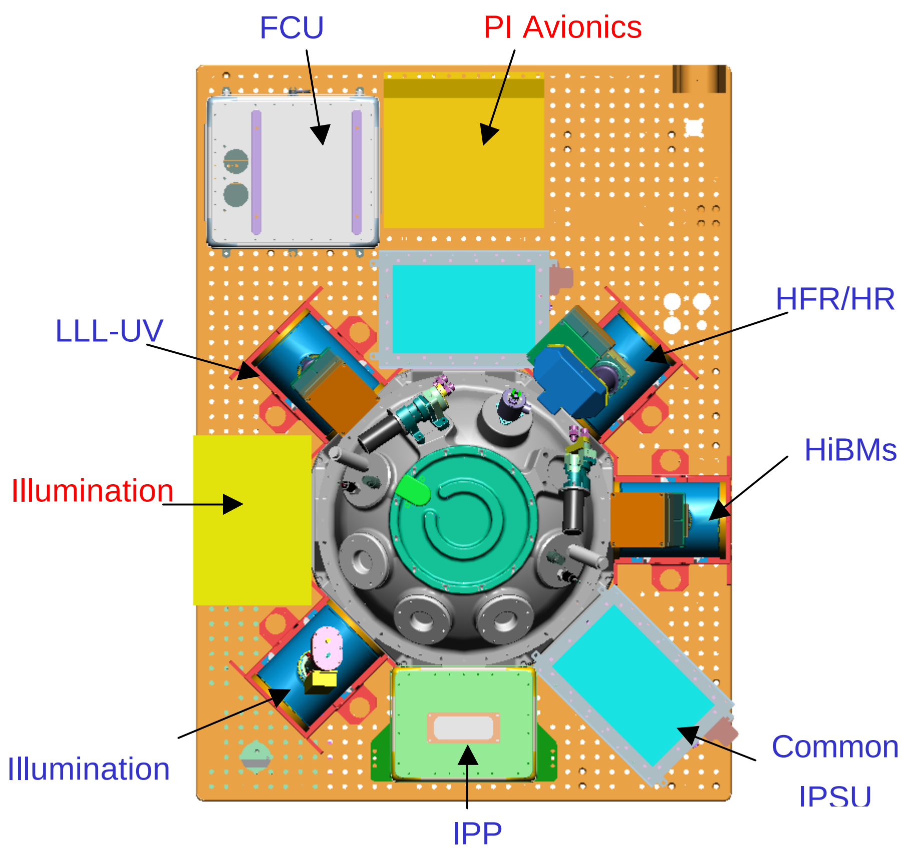
Requirement Types: ***Experiment Measurements***	**SRD Requirements for c8:** ***Sooting and Radiative Effects in Droplet Combustion (SEDC)***	**FCF Capabilities**	**Compliance Comments**
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate			*Requirement shows in SRED for c8.*
Other Experiment Measurements			

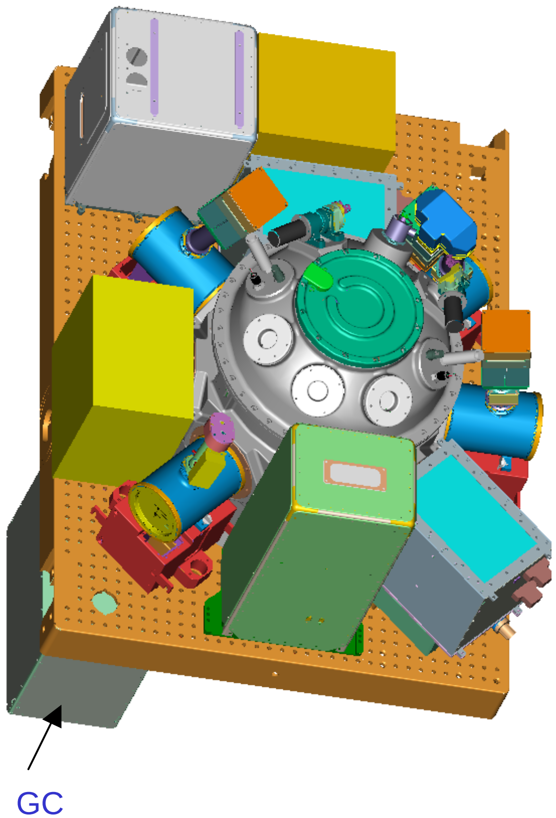
Requirement Types: ***Data Management***	**SRD Requirements for c8:** ***Sooting and Radiative Effects in Droplet Combustion (SEDC)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization			
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.		SVF and soot temperature data is provided sequentially by HiBMs package. Other packages can performed simultaneous measurements.	
Other Data Management			

Requirement Types: ***Operations***	**SRD Requirements for c8:** ***Sooting and Radiative Effects in Droplet Combustion (SEDC)***	**FCF Capabilities**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing			
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)	Fuel purity verification before and after flight. Calibration of two-wavelength pyrometry system using a blackbody source.	Fuel purity to be verified by PI. 2-wavelength pyrometry using to be calibrated on the ground prior to CIR launch.	
Auxiliary data Primary environmental parameters ISS data			
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points			

Requirement Types: ***Operations***	**SRD Requirements for c8:** ***Sooting and Radiative Effects in Droplet Combustion (SEDC)***	**FCF Capabilities**	**Compliance Comments**
Crew operations Crew observations during sample exchange Crew observations during test runs **Other**			
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points			
Post-flight sample and hardware return			
Other Operations			

Proposed diagnostics layout





Science Requirements Document Summary for

Simplified Unsteady Burning of Contained Reactants (SUBCORE) (c9)

SRD Date: NA (draft req. from Gokoglu)

Principal Investigator: Dr. Frank Fendell

Project Scientist: Dr. Suleyman Gokoglu

Project Manager:

Experiment Objective:

To study planar diffusion flames in a simple configuration.

Experiment Summary:

To form and track a planar diffusion flame. The chamber is separated into two half heights, each filled with a gas mixture. One side is the fuel; the other side is the oxidizer. As the separator is removed, the gas mixture is ignited. Flame position is measured by temperature and imaging.

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c9:** ***Simplified Unsteady Burning of Contained Reactants (SUBCORE)***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions Volume Dimensions Shape	Nominal dimensions 10” x 10” x 3.5”; 1.75” half height. Rayleigh number < 1706/3, based on half-height and 10^{-5} g_o. Compatible with hydrogen, oxygen, and water. Capable of safely handling up to 9.5 atm. Separator: Thickness between 200 microns and 1.1 mm. Retraction time between 0.15 and 0.2 s, with smooth acceleration to 100 – 125 cm/s and with as much of the retraction occurring at as close to constant speed as possible. Reusable. Impervious to and compatible with H2 and O2. Gas leakage from each half volume of the chamber is less than 0.5% by mole of the half-volume contents (to and from all sources). Planar flame formed in the chamber must have less than +/- 2.0 mm variation in height over the 10” x 10” cross-section of the chamber for the position of the maximum measured gas temperature.	Test section is PI-provided H/W (CIA). Chamber dimensions available for PI H/W: 396 mm Diameter 600 mm Length	CIR chamber can withstand leak from sub-chamber. Pressure rise in CIR chamber would be 8 psid.
Fuel State Physical state of fuel Storage Distribution Mixing Handling	Hydrogen. Uncertainty of the composition of each major constituent is less than +/- 0.5% by mole preferable, less than +/- 1% acceptable. Trace impurities less than 0.5 ppm for O2 and less than 2 ppm for other species. Fuel may be diluted with helium, neon, argon, or xenon. Equivalence ratio 0.15 to 0.4. Prior to separator removal, gas velocity must be less than 1 cm/s.	Fuel is PI-provided. Fuel can be delivered to chamber through the Fuel/Premixed Fuel Supply Manifold in either 1L or 2.25L bottles.	

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c9:** ***Simplified Unsteady Burning of Contained Reactants (SUBCORE)***	**FCF Capabilities**	**Compliance Comments**
Ignition Igniter Power Control Geometry	10 spark ignitors. 50 to 370 volts. 1 msec duration. Timing precision +/- 1 msec. Spaced 1 cm off the sidewall facing the slit-containing sidewall, within 1-2 mm of the centerplane between the end wall, 2.27 cm apart. Distance between spark electrodes is 0.016 in.	Ignitor is PI H/W (CIA) controlled by PI Electronics Enclosure via chamber IRR.	
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	Less than 1 (+ 0.5) x 10^{-5} g_o in all directions. Jitter frequency less than 10 Hz.	CIR will operate with an active ARIS.	
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	Prior to separator removal, maintain in each half volume a range of 0.5 to 1 atm, +/- 3% and a maximum pressure difference between two half volumes is 2 Pa. Capable of safely handling up to 9.5 atm. Evacuate chamber, after post-burn gas sampling, to less than 5 Pa.	The chamber MDP is 9 atm. Additional containment to handle 9.5 atm must be provided by PI H/W (CIA)	
Operating Temperature Gas temperature control Condensed phase fuel temperature control	Prior to separator removal a wall temperature of 15 to 30 degrees C +/- 1 degree C; maximum temperature difference between two half volumes is 5 degrees C preferable, 10 degrees C acceptable; maximum temperature difference between chamber wall and gases in chamber is 5 degrees C preferable, 10 degrees C acceptable.	Chamber interior temperature will be maintained within the range of the delivered gas temperature.	

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c9:** ***Simplified Unsteady Burning of Contained Reactants (SUBCORE)***	**FCF Capabilities**	**Compliance Comments**
Oxidizer Composition Components Range Accuracy	Oxygen. Uncertainty of the composition of each major constituent is less than +/- 0.5% by mole preferable, less than +/- 1% acceptable. Trace impurities less than 0.5 ppm for O2 and less than 2 ppm for other species. Oxygen may be diluted with helium, neon, argon, or xenon. Equivalence ratio 0.15 to 0.4. Prior to separator removal, gas velocity less than 1 cm/s.	Oxidizer and diluent are PI-provided delivered in combinations of any of the 3 standard oxidant bottles: 1L (85% for O2), 2.25L (50% for O2) or 3.8L (30% for O2).	*SRED Fig. C5a indicates max oxygen of 50%.*
Fuel Flow Flow rate Range Duration Accuracy Stability	NA		
Oxidizer Flow Flow rate Range Duration Accuracy Stability	NA		
Number, duration of tests			*SRED App. B indicates min. of 20 test points. SRED Fig. C7 indicates 15-25 test points.*
Other Experiment Conditions			

Requirement Types: *Experiment Measurements*	SRD Requirements for c9: *Simplified Unsteady Burning of Contained Reactants (SUBCORE)*	FCF Capabilities	Compliance Comments
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	Separator edge and flame tip positions, chamber top-wall view. 1) One 3"-long x 1"-wide plane centered top to bottom, long side along separator-translation direction and approximately centered between the ignitor and separator-exit sidewalls, short side perpendicular to separator-translation direction and 2" – 3" off the centerline between other sidewalls. 2) One 3"-long x 1"-wide plane centered top to bottom, short side along separator-translation direction and 1"-2" away from the separator-exit sidewall, long side perpendicular to separator-translation direction and centered between other sidewalls. Sampling frequency greater than or equal to 30 Hz. Resolution +/- 1.0 mm.	CIA must be oriented to comply with FOV orientation requirements. CIA must provide optical material on chamber walls for viewing access. 1 color view provided. 30 fps ; 6 to 35 cm sq. FOV ; 230 µm to 1.4 mm resolution at 50% modulation depending on zoom position (290µm @ 75mm FOV). Depth of field depending on FOV and adjustable iris setting. 2 lux sensitivity at full aperture. 1 B/W intensified view provided; 500 - 875nm spectral range; 30 fps; 4.2 to 21.2 cm sq. FOV; 83 to 413 µm resolution (at 50% modulation) depending on zoom position. (146 µm at 75mm FOV; due to FOV centerline offsets-175mm FOV may be required w/ 340µm resolution). Depth of field depending on iris setting and FOV. Gain can be set to minimum if intensification is not required.	*Two views requirement not in SRED.*

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c9:** ***Simplified Unsteady Burning of Contained Reactants (SUBCORE)***	**FCF Capabilities**	**Compliance Comments**
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration		Mid-IR imager provided, see 16.	*SRED shows IR imaging required for c9.*
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration			
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate			

Requirement Types: *Experiment Measurements*	**SRD Requirements for c9:** ***Simplified Unsteady Burning of Contained Reactants (SUBCORE)***	**FCF Capabilities**	**Compliance Comments**
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate	2-D profile of the flame temperature and thereby flame position as a function of time on the chamber sidewall view at two locations. 1) On the fuel side, on 1"-high x 1" wide column centered with respect to the lateral, front, and back sidewalls. 2) On the fuel side, one 1"-high x 1" wide column next to the separator-exit sidewall and centered with respect to the front and back sidewalls. Range 1300 to 2600 K. Precision +/- 1.0 mm. Sampling frequency 10 Hz Resolution +/- 0.1 mm.	One Mid-IR view provided 183 x 138 mm FOV; 60 fps. 263 to 1773 K . 1.1mm resolution. Package is modular design: a PI-provided lens with 25mm FOV would give 350µm resolution. PI must provide the mean within the CIA to transmit appropriate wavelengths.	SRED does not specify 2 views
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	Chamber pressure. Range 2 to 50,000 Pa. (0.5 – 9 atm) Precision 0.15% of reading. Sampling frequency 30 Hz.	CIR complies	
Chemical composition Species Range Accuracy	Gas samples after waiting at least 60 minutes after the test for uniform gas mixing. Gas constituents, including water, O2, H2, and inert gases.	GC provided	
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity			

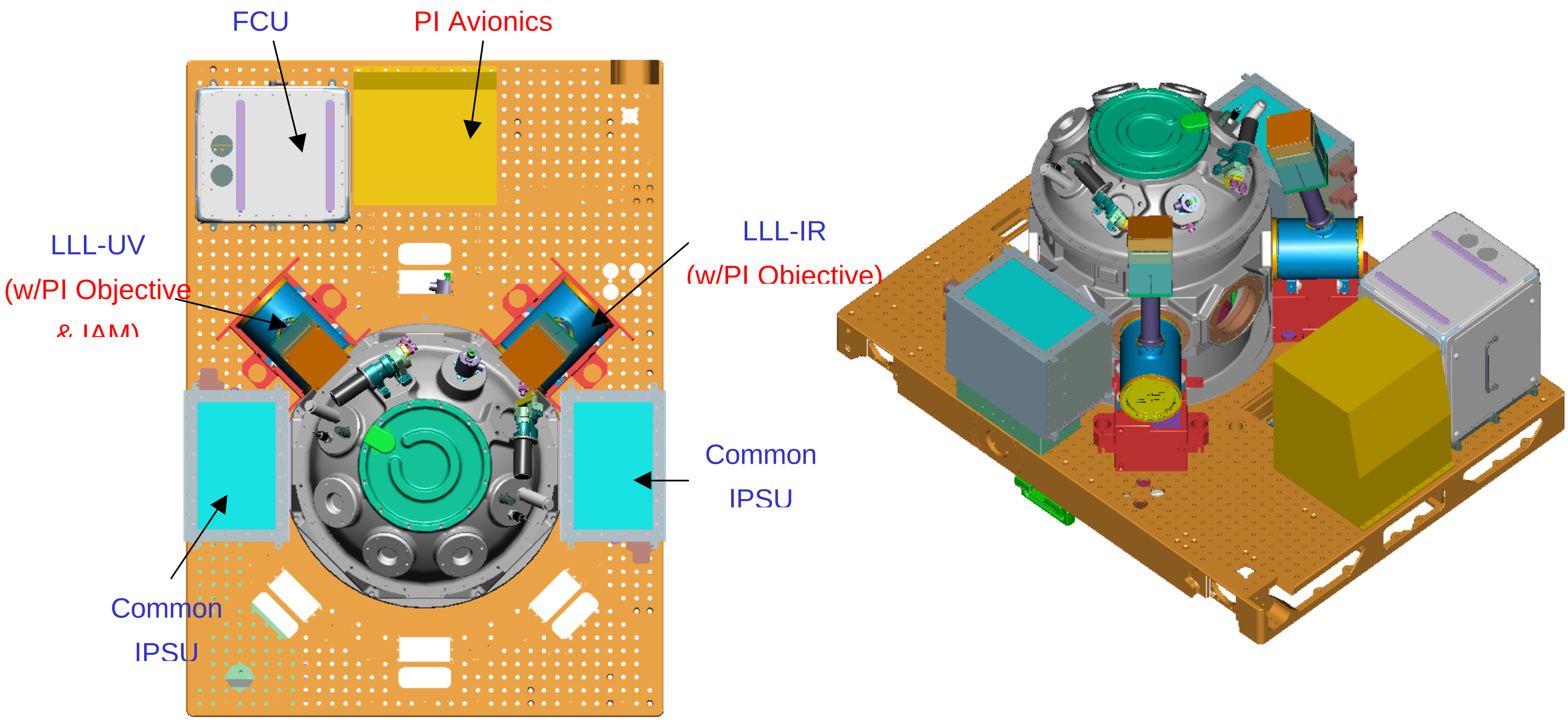
Requirement Types: ***Experiment Measurements***	**SRD Requirements for c9:** ***Simplified Unsteady Burning of Contained Reactants (SUBCORE)***	**FCF Capabilities**	**Compliance Comments**
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity			
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles			
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles			
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate			
Other Experiment Measurements	Data to be collected at least 15 sec before ignition and continuing until at least 3 min after ignition.	CIR complies	

Requirement Types: ***Data Management***	**SRD Requirements for c9:** ***Simplified Unsteady Burning of Contained Reactants (SUBCORE)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization			
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.		Support for 4 simultaneous imaging packages is provided.	
Other Data Management			

Requirement Types: ***Operations***	**SRD Requirements for c9:** ***Simplified Unsteady Burning of Contained Reactants (SUBCORE)***	**FCF Capabilities**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing			
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)			
Auxiliary data Primary environmental parameters ISS data			
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points			

Requirement Types: ***Operations***	**SRD Requirements for c9:** ***Simplified Unsteady Burning of Contained Reactants (SUBCORE)***	**FCF Capabilities**	**Compliance Comments**
Crew operations Crew observations during sample exchange Crew observations during test runs Other			
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points			
Post-flight sample and hardware return			
Other Operations			

Proposed diagnostics layout



Science Requirements Document Summary for

Solid Inflammability Boundary at Low Speed (SIBAL) (c10)

SRD Date: June 1996. Anticipated changes for revised draft are in *italics*.

Principal Investigator: Prof. James S. T'ien
Project Scientist: Dr. Paul V. Ferkul
Project Manager: David Frate

Experiment Objective:

The primary objective of the SIBAL experiment is to verify the theoretically predicted extinction boundary in concurrent-flow flame spread across a thin solid fuel, using oxygen percentage and flow velocity as coordinates. In particular, the low-speed quenching limits and the existence of the critical oxygen flammability limit are sought.

Experiment Summary:

A thin solid fuel ribbon is placed into a low-speed flow duct. After the gas flow is established, the sample is ignited using a hot wire. As the fuel is consumed by the flame, the ribbon moves to supply fresh fuel in order to maintain the flame at a fixed position in the flow duct. The flammability boundary is mapped out by varying the oxygen concentration or the gas flow rate and observing flame extinction. Measurements of the flame shape, structure, temperature, and heat release, and the fuel burnout rate are required.

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c10:** ***Solid Inflammability Boundary at Low Speed (SIBAL)***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions Volume Dimensions Shape	Rectangular flow duct. Top and bottom walls from 4 to 5.5 cm from the fuel. *Flow duct is currently 11 cm x 11 cm.* Side walls TBD from the fuel. Walls should have low reflectivity less than 0.05 from 2 to 21 microns. For two tests, one wall with reflectivity > 0.5 over 2 to 21 microns must be used. Meeting the reflectivity requirement exactly is not critical; the emission characteristics of the wall must be known. Uniform velocity profile (without sample) within 5% across the flow area, away from the walls and fuel take-up duct. Flow duct walls not to exceed ambient temperature plus *TBD* C.	Flow duct is PI-provided H/W (CIA). Chamber dimensions available for PI H/W: 396 mm Diameter; 600 mm Length	[SIBAL flow duct]. Corresponding flow velocities can be achieved if a 10 cm x 10 cm flow duct is used.
Fuel State Physical state of fuel Storage Distribution Mixing Handling	Solid thin sheets on a spool. Fuel candidate is cellulose/fiberglass weave. Controlled moisture content. *3* to 10 cm wide. Exposed length of 20 to 30 cm. *Current length is 30 cm.* Flatness of +/- 1 mm across the fuel width. Automatic fuel feed into the flame to +/- 1 mm. Sample size long enough to provide multiple burns at different conditions.	Fuel is PI-provided. Ability to supply several samples is PI-provided (CIA).	[Fuel ribbons on a solid fuel delivery system].
Ignition Igniter Power Control Geometry	Multiple ignitions. No disturbance to flame or flow field when not in use.	Ignitor is PI-provided (CIA).	[Retractable hot wire used in ground-based testing.]

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c10:** ***Solid Inflammability Boundary at Low Speed (SIBAL)***	**FCF Capabilities**	**Compliance Comments**
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	< 10-4 g/go quasi-steady	CIR will operate with an active ARIS.	
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	1 +/- 0/05 atm.	Chamber pressure will be controlled by FCU	[Pressure control required during combustion].
Operating Temperature Gas temperature control Condensed phase fuel temperature control	Bulk temperature of the gas and solid fuel should be 25 +/- 5 C during the test.	CIR complies, provided that temperature requirement is within the range of cabin temperature.	
Oxidizer Composition Components Range Accuracy	Between 10 and *30%* oxygen by mole at 0.25% increments. During a test, oxygen index maintained to with 1% of the set value. Relative humidity of bulk gas lower than 50%.	Oxidizer is PI-provided in standard CIR bottle sizes and concentrations: 1L 85%O2, 2.25L 50%O2 or/and 3.8L 30% O2.	[FOMA-provided gases]. *SRED App. B and Fig. C7 indicate 10-21% oxygen.*
Fuel Flow Flow rate Range Duration Accuracy Stability	N/A		

Requirement Types: ***Experiment Operating Conditions***	**SRD Requirements for c10:** ***Solid Inflammability Boundary at Low Speed (SIBAL)***	**FCF Capabilities**	**Compliance Comments**
Oxidizer Flow Flow rate Range Duration Accuracy Stability	0 to 15 cm/s. For 0 to 4 cm/s, adjustable to within 0.25 cm/s. For 4 to 15 cm/s, adjustable to within 0.5 cm/s.	The maximum flow rate of 90 SLM (1500 scc/s) can be delivered for 15 minutes. To achieve 15 cm/s velocity, a flow duct of 10 cm x 10 cm must be used. Varying oxygen flows are limited to 60 SLM (1000 scc/s) and can be delivered for 15 minutes. Based on a 10 cm x 10 cm flow duct, the corresponding velocity would be 10 cm/s.	Exact flow durations are not specified in the SRED. [Length of test may be limited by gas volume (flow rate and flow duct cross section)].
Number, duration of tests	14 tests (7 repeats). Each test is 20-30 min. Six go/no-go pairs: three at constant flow), three at constant %O2, one with reflective wall. *Number of repeat tests will decrease but effects of fuel width will be studied.*	Bottle and venting combinations can be determined for the required number of tests points.	The FOMA can only deliver flows for a maximum of 15 min.
Other Experiment Conditions	Extinguishment on command. Capability of removing char and ash. Condensation on windows is undesirable.	Extinguish command can be uplinked. CIA removal is required so char and ash can be removed form chamber walls.	

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c10:** ***Solid Inflammability Boundary at Low Speed (SIBAL)***	**FCF Capabilities**	**Compliance Comments**
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	**Color images**: Framing rate of no lower than 10 fps. Field of view at least 10 cm x 10 cm. Resolution of 0.2 mm. Schlieren: (probably being deleted). **CH emission images**: Flame zone edge view. Framing rate at least 1 fps. Field of view at least 10 cm x 10 cm. Resolution of 0.2 mm. Wavelength of 431 nm.	1 color view provided. 10 fps at max. resolution; 20 min. run time; 6 to 35 cm sq. FOV ; 115 µm to 700µm resolution at 50% modulation depending on zoom position. (At 10 cm. FOV, resolution is 195µm); depth of field depending on adjustable iris setting and FOV. 2 lux sensitivity at full aperture. 1 B/W intensified near-IR view provided; 30 fps; 4.2 to 21.2 cm sq. FOV; 83 to 413 µm resolution (at 50% modulation) depending on zoom position. (195 µm res. @ 100mm FOV). Depth of field depending on iris setting. Gain can be set to minimum if intensification is not required. Spectral sensitivity 280 to 700 nm @ 10% of peak sensitivity. Bandpass filter at 431nm provided.	

Requirement Types: *Experiment Measurements*	SRD Requirements for c10: *Solid Inflammability Boundary at Low Speed (SIBAL)*	FCF Capabilities	Compliance Comments
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	**Species images**: Flame zone edge view. CO2, H2O, and soot fields. Framing rate at least 1 fps. Field of view at least 10 cm x 10 cm. Resolution of 0.2 mm. Wavelengths of 4.3 micron (CO2), 1.87 micron (H2O), 1.6 micron (soot), and 3.8 micron (soot).	1 mid-IR view provided. 183 x 138 mm FOV 60 fps; 1 to 5 µm spectral sensitivity with motorized bandpass filter at selected wavelengths. mm resolution Package is modular design: a PI-provided lens w/100mm FOV would give 820µm resolution.	
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	**OH emission images**: Flame zone edge view. Framing rate at least 1 per s. Field of view at least 10 cm x 10 cm. Resolution 0.2 mm Wavelength of 310 nm.	1 B/W intensified UV view provided; 30 fps; 4.2 to 21.2 cm sq. FOV; 83 to 413 µm resolution (at 50% modulation) depending on zoom position. (195 µm res. @ 100mm FOV). Depth of field depending on iris setting. Gain can be set to minimum if intensification is not required. Spectral sensitivity 280 to 700 nm @ 10% of peak sensitivity. Bandpass filter @ 310nm	

Requirement Types: ***Experiment Measurements***	**SRD Requirements for c10:** ***Solid Inflammability Boundary at Low Speed (SIBAL)***	**FCF Capabilities**	**Compliance Comments**
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate	**Global**: Sampling rate at least 1 Hz. Accuracy +/- 1 C. **Retractable flame**: 1 to 3 measurements. Sweep upon command through the flame leading edge region.	Temperature point measurement is PI-provided (CIA)	
Temperature field measurements Location Field of view Spatial resolution Temperature range Temperature resolution Sampling rate	Fuel surface temperature. Field of view 10 x 10 cm. Spatial resolution 0.2 mm. Resolution +/- 5 C. Sampling rate of 1 Hz.	Same imager as 13. Temperature range 263 to 1773K Temperature measurement accuracy +/- 2% or 2C.	
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	Sampling rate at least 1 Hz. Accuracy +/- 0.02 atm.	CIR complies	
Chemical composition Species Range Accuracy	Humidity +/- 5%. Oxygen mole fraction +/- 0.1%	GC provided	

Requirement Types: *Experiment Measurements*	SRD Requirements for c10: *Solid Inflammability Boundary at Low Speed (SIBAL)*	FCF Capabilities	Compliance Comments
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity	See 13. above.	Same imager as 13.	
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity	Several in the top wall of the duct. Range of 0 to 1 W/cm2. Details TBD.	Radiometers are PI-provided.	
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles	In flow duct. Range 0 to 15 cm/s. Plug flow velocity +/- 0.25 cm/s for speeds less than 4 cm/s. Plug flow velocity +/- 0.5 cm/s for higher speeds.	PI-provided H/W (CIA)	

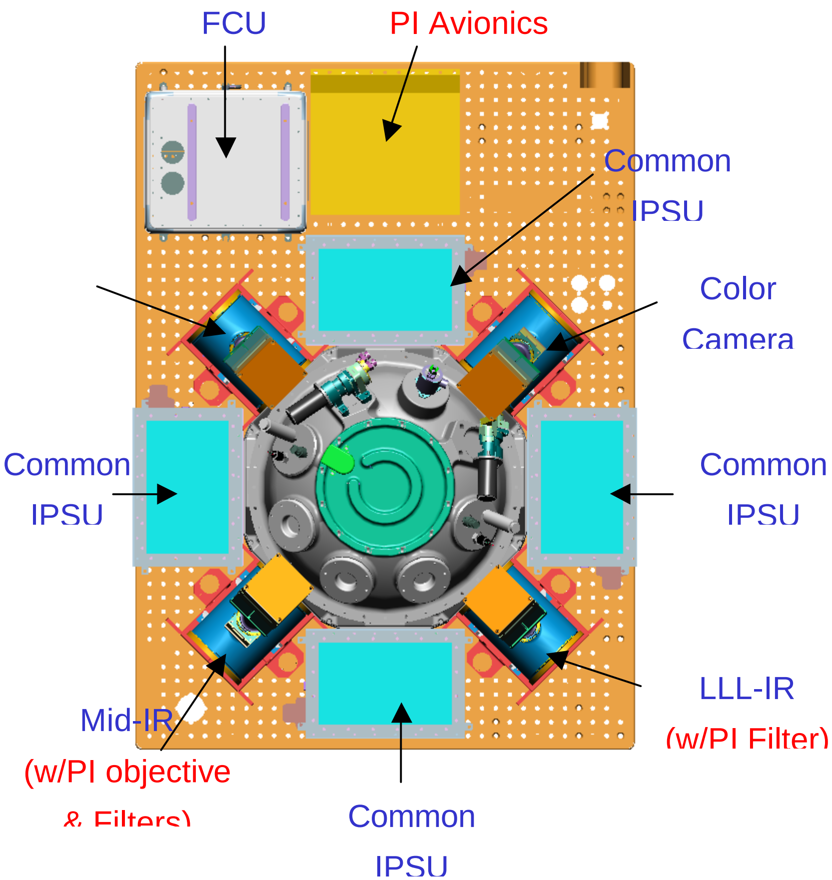
Requirement Types: ***Experiment Measurements***	**SRD Requirements for c10:** ***Solid Inflammability Boundary at Low Speed (SIBAL)***	**FCF Capabilities**	**Compliance Comments**
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles	N/A		
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate			
Other Experiment Measurements	Fuel burnout rate.		

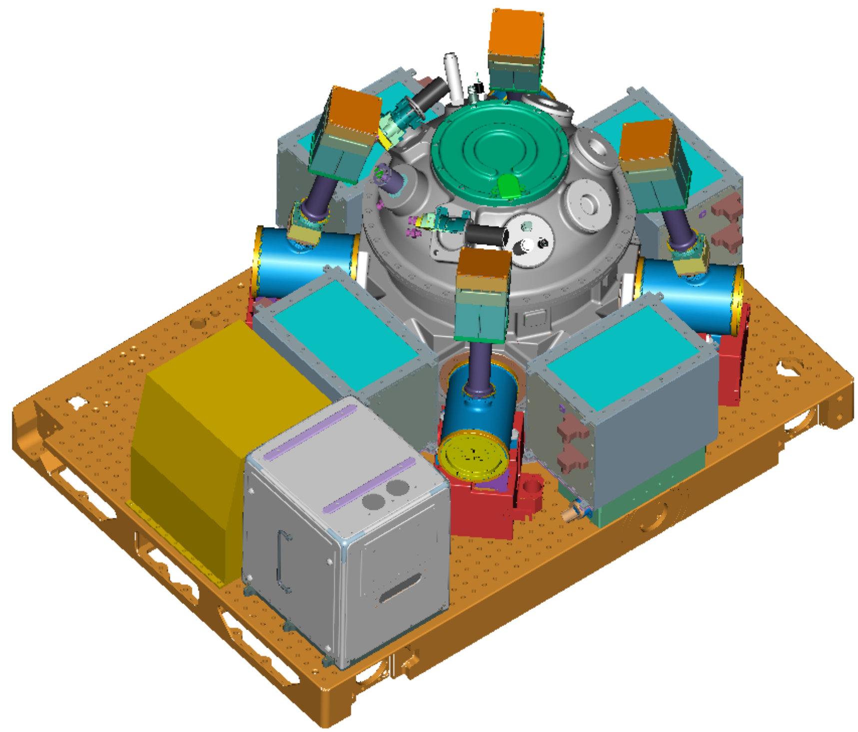
Requirement Types: ***Data Management***	**SRD Requirements for c10:** ***Solid Inflammability Boundary at Low Speed (SIBAL)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	The CH, OH, CO2, H2O, and two soot images all need to be time synched to 1/30 s. All data for a given test to within 1/30 s.	All cameras and acquisition systems will be synched to at least 1/30 s. All images are time stamped with accuracy better than 10 ms. Some images are sequentially obtained (CH and OH; CO2, H2O and soot).	
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.	Field: 8 Color image, CH emission, OH emission, CO2, H2O, two soot fields, surface temperature. Single sensor: 8-12 Pressure, global temperature, humidity, oxygen mole fraction, plug-flow velocity, radiometers (1-3), flame temperature (1-3), fuel burnout rate.	Only 4 camera views can be obtained simultaneously.	
Other Data Management			

Requirement Types: ***Operations***	**SRD Requirements for c10:** ***Solid Inflammability Boundary at Low Speed (SIBAL)***	**FCF Capabilities**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing			
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)			
Auxiliary data Primary environmental parameters ISS data			
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points			
Crew operations Crew observations during sample exchange Crew observations during test runs Other			

Requirement Types: *Operations*	SRD Requirements for c10: *Solid Inflammability Boundary at Low Speed (SIBAL)*	FCF Capabilities	Compliance Comments
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points			
Post-flight sample and hardware return			
Other Operations			

Proposed diagnostics layout





Science Requirements Document Summary for

Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D) (c11)

SRD Date: October 1998

Principal Investigator: Dr. Takashi Kashiwagi, NIST

Project Scientist: Dr. Sandra L. Olson

Project Manager: Ms. Hanh N. Do

Experiment Objective:

The objective of this experiment is to investigate the processes that control the transition from ignition to subsequent flame spread for solid fuels. The effects of external radiant flux distribution and flow velocity, sample configuration and characteristics, and oxygen concentration will be studied through a set of experiments that vary these parameters. The results will be used to validate a computer model that predicts initiation of fire and its growth in microgravity, and eventually in normal gravity.

Experiment Summary:

Samples of paper and polymethylmethacrylate (PMMA) will be placed into a flow duct. Once the gas flow is established, the sample will be radiantly ignited in either a 2-D (line) or 3-D (circle) configuration. The ignition and transition phases will be studied. Measurements include ignition shape and time, flame shape, structure, color, and spectral emissions, gas and surface temperature, soot particles, and the audio signature.

Requirement Types: **Experiment Operating Conditions**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions Volume Dimensions Shape	Flow duct, rectangular or octagonal, 16 cm h, no less than 12 cm w, no less than 24 cm length (along CIR chamber axis). Internal wall is black in color, with smooth walls and flow straighteners upstream and downstream of the test section. Front windows transmitting > 90% from 0.4 to 11 microns. One edge window transmitting > 95% from 0.4 to 5 microns. Other edge window transmitting > 95% over visible wavelengths.	Flow duct is PI-provided H/W (CIA). Chamber dimensions available for PI H/W: 396 mm Diameter; 600 mm Length. IR window(s) is PI H/W. Chamber design supports window changeout. CIR windows comply with visible and mid-IR spectrum requirements.	[NaCl window suggested for surface view transmission of ignition beam, to minimize power requirements].
Fuel State Physical state of fuel Storage Distribution Mixing Handling	Char forming material (paper) with 20, 30, 60, and 100 g/m2 surface density, 10 x 14 cm for 3D, 7 x 14 cm for 2D. Non-char forming material (PMMA), 0.08 cm thick, 10 x 14 cm for 3D, 7 x 14 cm for 2D, MW 800,000. Reference grid (1 cm x 1 cm) lines on the sample surface, black on white paper, white scribe lines on PMMA. Smoldering paper samples made of Whatman 44 filter paper samples doped with potassium acetate. Sample holder to support sample and hold it along the centerline of the flow duct without impeding viewing of the sample and without obstructing the flow. Maximum of 0.5 mm protrusion, < 1.5 mm thick, < 3% reflectance. Samples stored in a dry environment prior to use. Unmounted spare samples.	Fuel PI-provided H/W (CIA).	

Requirement Types: **Experiment Operating Conditions**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Ignition Igniter Power Control Geometry	External non-intrusive source to cause ignition in 2D and 3D configurations with the same Gaussian flux distribution (different total ignition energy). Flux distribution within 5% temporal fluctuations at each location. Minimum peak flux of 10 W/cm2. Minimum half width diameter (1/e) of 0.5 cm and 1.2 cm (2D and 3D) at the sample location. Temporal measurement of the ignition source energy output, at 100Hz with an accuracy of +/- 2%. Duration variable over a range of TBD s in 0.1 s increments. The location of the irradiated center can be varied lengthwise from the center to 3 cm downstream from the center at a step of 1 cm.	Ignition system is PI-provided. Controls are provided by PI electronics enclosure. PI provides appropriate window material for ignitor energy transmission Package modifications are PI responsibility supported by modular CIR diagnostics design.	[Wavelength of ignition source must not interfere with imaging diagnostics (visible and mid-IR)]. *Some diagnostics capability may be compromised in order to accommodate the required ignition system.* May be able to accommodate ignition system by replacing folding mirror module of the Color Package with a PI-provided beamsplitter module that reflects the color view and transmits the igniter energy.
Acceleration and Vibration Quasi-steady limits Vibratory disturbance limits Transient impulse limits	Maximum of 1 x 10-4 g.	CIR will operate with an active ARIS.	

Requirement Types: **Experiment Operating Conditions**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Operating Pressure Pressure range Pressure containment (max. prior to or during combustion) Pressure control	1.0 +/- 0.05 atm.	Chamber pressure will be controlled by FCU.	[Actively controlled]
Operating Temperature Gas temperature control Condensed phase fuel temperature control	Flow temperature at the duct inlet does not vary more than +/- 10 K around its initial temperature during a test. Initial temperatures between tests will not vary by more than +/- 10 K from 295 K.	Operating temperature range is within the cabin temperature range.	[Actively controlled]
Oxidizer Composition Components Range Accuracy	Prepared to 20.9% +/- 0.3% oxygen concentration in nitrogen, known to +/- 0.1%. Acceptable levels of residual gases for the case of reusing the test gas are unburned hydrocarbon < 0.1 vol%, CO_2 < 0.2 vol%, and water < 20% RH.	Oxygen/diluent concentrations can be delivered by combinations of any of the 3 standard oxidant bottles: 1L 85%O_2; 2.25L 50%O_2 or/and 3.8L 80%O_2 all with balanced N_2 (ISS-provided).	[Actively controlled] *SRED App. B and Fig. C5a indicates 21-50% oxygen.*
Fuel Flow Flow rate Range Duration Accuracy Stability	N/A		

Requirement Types: Experiment Operating Conditions	SRD Requirements for c11: *Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)*	FCF Capabilities	Compliance Comments
Oxidizer Flow Flow rate Range Duration Accuracy Stability	0 to 20 cm/s +/- 0.20 cm/s or 10%, whichever is greater, at the beginning of the sample location in the duct. Minimum flow velocity of 0.5 cm/s, with a PI-provided fan. Two fans may be used to capture the range of flows required.	If flow through capability is desired, FOMA max flow rate of 90 SLM will result in a duct velocity of only 7.8 cm/s. Experiment provided fans would be required to re-circulate the gases within the chamber and produce the higher flow velocities required through the duct.	[CIR flow system will recirculate/scrub combustion products and replace oxygen depleted during experiment with venting to maintain pressure].
Number, duration of tests	27 paper samples (3 repeats). 3 smoldering samples. 19 PMMA samples (4 repeats). Up to 1 min for paper and 6 min. for PMMA samples. Up to 10 min for smoldering samples.	PI must provide the ability to accommodate multiple samples. Tests durations can be supported by CIR data acquisition system. Flow through conditions at max. FOMA capability (7.8 cm/sec) could last up to 15 min. Time limits using sealed chamber re-circulated flow as within FOMA capabilities.	[Spare samples (un-mounted, un-instrumented) 10 paper, 10 PMMA 2 smolder] *SRED App. B and Fig C7 indicates 20 test points.* *SRED Fig C7 indicates max. duration of 1200 sec (20 min).*

Requirement Types: Experiment Operating Conditions	SRD Requirements for c11: *Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)*	FCF Capabilities	Compliance Comments
Other Experiment Conditions	Flame extinguishment to be achieved within 5 s after its activation. Extinguishment not to disturb the residual sample surface, to reduce cleaning requirements and preserve samples for post-flight analysis.	Desired methods for extinguishment are within FOMA capabilities. Use of inert gas to extinguish would require the use of the N2 manifold, thereby reducing the max. flow through rate to 60 SLM. This results in a duct velocity of 5.2 cm/s.	[Inert gas replacement, flow deactivation, or chamber evacuation].

Requirement Types: **Experiment Measurements**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Visible Imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	**General requirements**: Resolution of 0.25 mm around the irradiated area and 0.5 mm for the rest of the region. Recording about 15 s before a test and an event marker at the onset of irradiation. Flame images have a higher priority than char images.	CIR response to the resolution requirements are shown below in the individual camera package capabilities descriptions. Start recording is PI controllable. Event onset record can be sent through the PI electronics enclosure to the IOP for recoding or stamping.	

Requirement Types: Experiment Measurements	SRD Requirements for c11: *Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)*	FCF Capabilities	Compliance Comments
	Low light level color image, edge view: Visualize the flame growth behavior. Low magnification over the entire sample length to determine flame size, stand-off distance, and growth rate. For all samples, even smoldering, to observe sample flatness.	1 color view provided however, recommend using for fuel surface view-UML concept permits to configure as desired (See surface view section for Color Package capabilities). This requirement is not satisfied if color camera package is used to comply with color image surface view. The LLL near-IR Package could be considered for this measurement: 400-900nm spectral range at 10% points; 42-212mm sq. FOV; 83-417µm resolution	*Today's technology might not support this requirement. Pseudocolor might be an option if a camera with color filter wheel is used. If PI uses an analog unit, a mean to provide a digital signal into the IPSU is required and the IPSU image acquisition module may have to be changed..* PI may be able to add filter wheel or tunable filter to LLL near-IR Package.

Requirement Types: Experiment Measurements	SRD Requirements for c11: *Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)*	FCF Capabilities	Compliance Comments
	Color image, surface view: Observe the growth of the flame and char front. For flaming experiments, flame image is more important than char image. Smoldering experiments shall record char pattern images. Must be able to see both the flame and the reference grids. Three-dimensional behavior obtained in combination with edge views. Image over the entire sample surface. FOV is the sample size Resolution of 0.5 mm. Flame intensities vary from bright flame shortly after ignition to a faint blue flame front. Autogain control is recommended.	1 color view provided. 2 lux sensitivity at full aperture (PI-provided, if grater sensitivity is needed). 30 fps 58-350mm sq. FOV; 230µm resolution at 50% modulation and full aperture. (550µm resolution @ 140mm FOV); Depth of field depending on adjustable iris setting. Autogain is provided.	
	Highspeed color images, edge view: Visualize the onset of ignition and behavior of the flame to the transition to flame growth. Measure the distance between the foot of the flame and the sample surface. Image is parallel to the sample surface. Field of view 4 cm x 3 cm height centered at the irradiated center. Resolution of 0.25 mm to measure a distance as short as 1 mm. Framing rate of 200 to 500 frames/s.	CIR does not support this capability. PI-provided.	*Today's technology might not support this requirement.* Use of HiBMs could be considered. 80mm dia. FOV PI could change: 1) tunable filter module to RGB filter module; 2) camera to HFR/HR camera to get 90 filed/sec color images at 30 fps. 400µm resolution in binned operation.

Requirement Types: **Experiment Measurements**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
	Sample surface illumination: Required to observe the reference grids and char front with respect to flame shape during the fire growth period. Uniform to within 25% over the sample surface. Shall not interfere with other diagnostic measurements.	Sample illumination is PI-provided (CIA)	[Red LEDs suggested]
Infrared imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	See 16.	See 16.	
Ultraviolet imaging Phenomenon of interest Framing rate Field of view Resolution Depth of field Sensitivity Wavelength(s) Duration	N/A		

Requirement Types: **Experiment Measurements**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Temperature point measurements Number of measurements Location Temperature range Temperature accuracy Sampling rate	**Two gas phase point measurements**: Location 2 mm +/- 0.25 mm above the sample surface at 3 cm +/- 1 mm from the irradiated center. Minimize conduction losses along the leads. Connectors located on the opposite side from the high speed photography and IRSA measurement. Range of 400 to 1500 K Accuracy of 2.5% of the peak expected flame temperature of 1500 K. Non-catalytic. 30 Hz sampling rate. **Four surface point measurements**: At the center of the ignition area, 2 cm +/- 1 mm from the ignition area both in downstream and upstream at the center line, and 5 cm +/- 1 mm upstream. All within one bead diameter of the surface. Connectors located on the opposite side from the high speed photography and IRSA measurement. Temperature range of room temperature to 650 K. Accuracy of +/- 25 K. 30 Hz sampling rate.	Point temperature measurements are PI-provided.	[Thermocouples. 0.002” wire size to minimize effect of intrusive wires on flames].

Requirement Types: **Experiment Measurements**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Temperature field measurements	Fuel surface temperature measurement during the radiative ignition and transition periods.	One Mid-IR view provided.	[Recommend that an IR camera with flame filter be used. Recommend 3.9 micron filter with 0.1 micron bandwidth].
Location	Minimum FOV is 8 cm width by 10 cm length.	183 x 138 mm FOV; 1.1mm resolution; 60 fps.	
Field of view	Spatial resolution is 0.5 mm.	263 to 1773 K.	
Spatial resolution	Temperature range is 420 to 1050 K.	Temperature measurement accuracy: +/-2% or 2C	
Temperature range	Accuracy is 3% of the expected peak temperature of 1050 K.	12-bit dynamic range	
Temperature resolution	One image as reference before the start of irradiation.		
Sampling rate	Framing rate and duration of data recording shall be variable depending on the experiment, so that a minimum of 600 frames are recorded. Maximum framing rate is 60 frames/sec. Longest recording duration is 5 minutes.	PI must provide the means within the CIA to transmit appropriate wavelengths.	
	Event marker at the onset of the start of irradiation as the time reference.	Filters are PI-provided (may be inserted into IR package using modular design concept.	
	Gas-phase temperature measurement (IRSA system being worked on by PI and colleagues). Multispectral array to image mid-IR combustion gases (edge view).	PI may be able to provide a selector mirror at the surface view window that would permit switching between IR and Color packages for recording and supporting ignition.	*Anticipate window access limitations for simultaneous views of the fuel surface.*

Requirement Types: **Experiment Measurements**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Pressure Number of measurements Location Sampling rate Pressure range Pressure accuracy	See 5 Pressure measurements not explicitly called out but implied by pressure control.	CIR will monitor chamber pressure.	CIR chamber pressure.
Chemical composition Species Range Accuracy	Oxygen concentration of the bulk flow at the inlet and outlet of the flow duct. Response time of 1 second. Resolution of 0.1%. Measurement 10 s before the start of irradiation.	Oxygen is PI-provided in standard CIR bottles.	
Soot Measurements Number of samples Location Spatial resolution Field of view Sensitivity	One TEM grid for six selected experiments (two paper, two PMMA, two smoldering). Grid mounted at the downstream end of the flow duct. Samples removed after each test.	PI H/W (CIA)	
Radiometry Number of measurements Location Field of view Sampling rate Wavelength(s) Sensitivity	N/A		

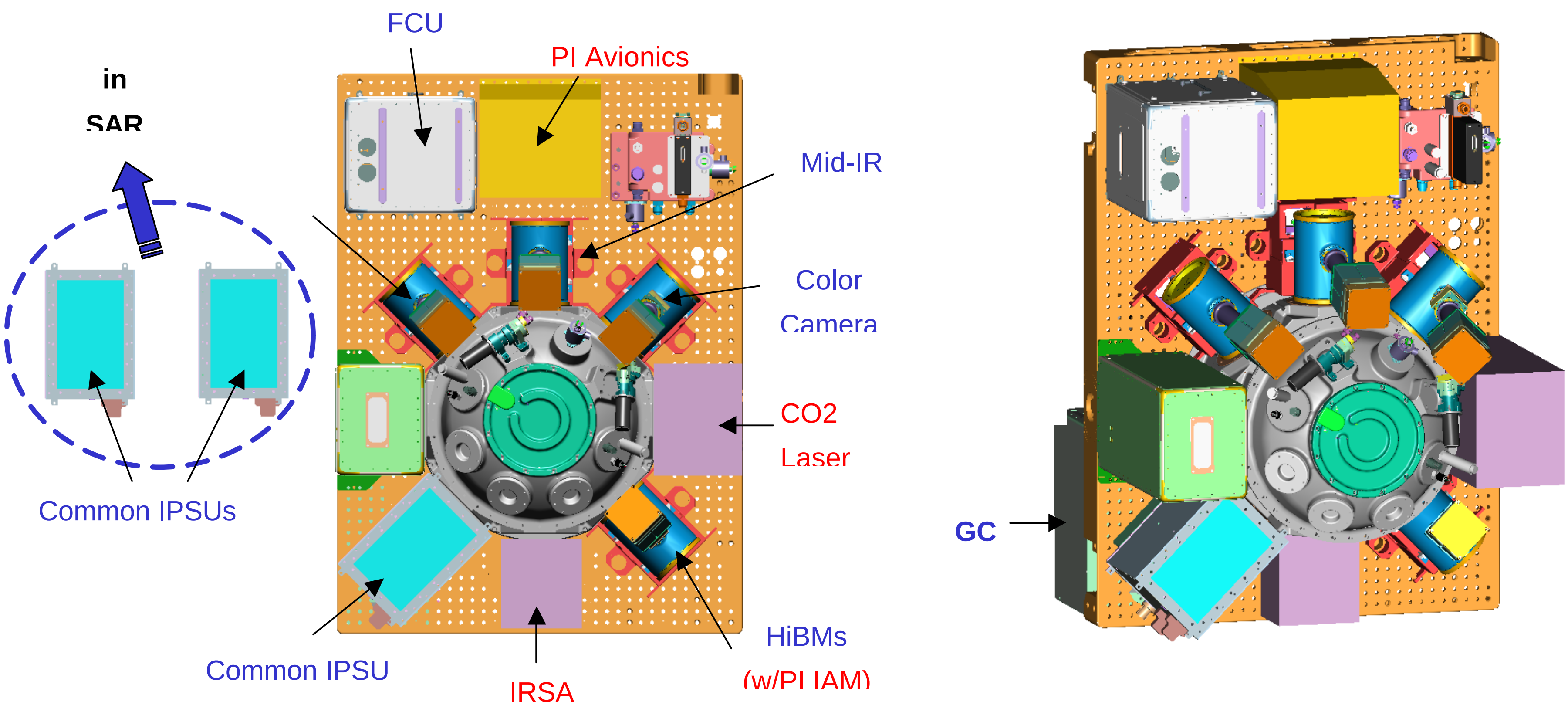
Requirement Types: Experiment Measurements	SRD Requirements for c11: *Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)*	FCF Capabilities	Compliance Comments
Velocity Point Measurements Number of measurements Location Sampling rate Velocity range Velocity accuracy Seed particles	N/A		[Fan RPM to set/verify flow rates]
Velocity Field Measurements Location Velocity range Velocity accuracy Field of view Sampling rate Seed particles	N/A		
Acceleration Measurements Accelerations range Accuracy Frequency range Sampling rate			
Other Experiment Measurements	**Audio signature**: Location inside the chamber. Data collection shall start 2 seconds before the onset of the radiation. Event marker on the data at the start of the irradiation. More details after further ground-based testing.	CIR color images will be time stamped. Microphone will be CIA H/W. Audio signal will be recorded and time stamped in the PI electronics enclosure. Post-test image and audio correlation will be required as a ground activity.	[Standard or miniature microphone, preferably tied to digital color imaging systems].

Requirement Types: **Data Management**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	CIR complies	
Simultaneous Measurements Number and identity of simultaneous field and single sensor measurements.	5 Field: Low light level color edge, color image surface (with illumination), highspeed color edge, infrared surface, IRSA. 12 Single sensor: Temperature (6), pressure, oxygen (2), audio, ignition energy, fan RPM. TEM grids.	CIR only offer the capability of simultaneously recording data from 4 camera packages. Other data recording will be achieved by a combination of PI and CIR H/W.	
Other Data Management	Digital infrared surface data provided along with software to create colorized temperature contour images. All other data provided to PI in SI engineering units. Data products to include as-run test matrix, including dates and times for each run, test number flow condition, sample, and unusual events, failure, and data losses for each run.	IR camera provides colorized temperature contour images.	

Requirement Types: **Operations**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Simulations Test sequences to be conducted on FCF simulators Test sequences to be conducted during mission timeline sequence testing			
Calibration, verification, and functional test data Type of data Time of testing (pre- or post-flight)	Surface temperature measurement camera calibration pre-and post-flight to verify accuracy levels.	Comply with pre-flight camera calibration for CIR-provided H/W.	
Auxiliary data Primary environmental parameters ISS data			
Telescience Near-real-time data downlink Imaging data downlink Near-real-time command uplink Parameters requiring real-time control during a test point Parameters requiring changes between test points	**Data downlinked**: Temperatures, pressure, ignition system output, fan revolution, oxygen analyzer outputs, digital imaging systems, status of hardware system. **Automated procedures**: Gas filling system, gas composition analysis, sample installation system, data transfer, data collection, test start, operations, and stop. **Commands**: Ignition and extinguishment. **Parameters changing between test points**: flow velocity, irradiated area and geometry, duration of ignition system, sample type, diagnostic alignments, shifting of the field of view, change in diagnostic scan rate.	CIR complies	

Requirement Types: **Operations**	**SRD Requirements for c11:** ***Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D)***	**FCF Capabilities**	**Compliance Comments**
Crew operations Crew observations during sample exchange Crew observations during test runs Other	Reloading and storing samples, mounting of spare samples in sample holders, cleaning chamber, replacing filters, diagnostics installation/adjustment, gas bottle changeout, window changeout, troubleshooting.	TBD	
Test point sequencing Sample experiment timeline and operations Grouping and prioritizing of test points Time between test points Time between groups of test points	Sample installation, verify installation contacts, gas mixture preparation, diagnostics activation, alignment and focus checks, flow activation, ignition system activation, ignition, ignition system deactivation, flame growth, flame extinguishment, flow deactivation, diagnostic deactivation, spent sample removal, filter changeout (selected tests), atmospheric scrubbing, data downlinking. Sample priority: paper samples, smoldering experiments, PMMA samples, spares. After TBD test points, data analysis for 1 week.	Some of these activities will be part of the on-orbit checkout procedure. PI CIA must provide ability to change out samples as well as provide crew procedures.	
Post-flight sample and hardware return	All tested sample residues to be returned to earth for analysis of degradation and bubbling. TEM grids returned to earth for microscopy analysis.	TBD	
Other Operations			

Proposed diagnostics layout



Appendix B – FIR Basis Experiments Compliance

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Science Requirements Document Summary for

Thin Film Fluid Flows at Menisci (f1)

Principal Investigator: Hallinan

Experiment Objective:

In general, the objective of the experiment is to investigate the behavior of capillary-driven heat transfer systems. More specifically, the objective is to understand mechanisms of fluid flow and characteristics of fluid spread in a film when the film is heated and provide support and data for the application of disjoining pressure gradient theory relative to describing the flow in a thin liquid film region. This will, in microgravity, extend the range of influence of the solid-liquid intermolecular interaction to film dimensions so that optical techniques can be applied. The experiment is also interested in the role of thermocapillarity on the shape, flow field, and temperature field for evaporating meniscus.

Experiment Summary:

An apparatus will be used in which a meniscus in a petri dish can be formed. A section encompassing the meniscus will be heated to engender the evaporation from the interface. The petri dish cover will have to employ condensation for overall system balance. The diameter of the test cell should be at least 10 cm with a 1-meter radius of curvature. The design of the cell must be such that the meniscus must be fixed in space. In addition, the heating of the cell must be uniform in the circumferential direction. The cell must be able to operate at a controllable average temperature. Contact line must be variable and controllable over a 2-cm range. The sample is pentane.

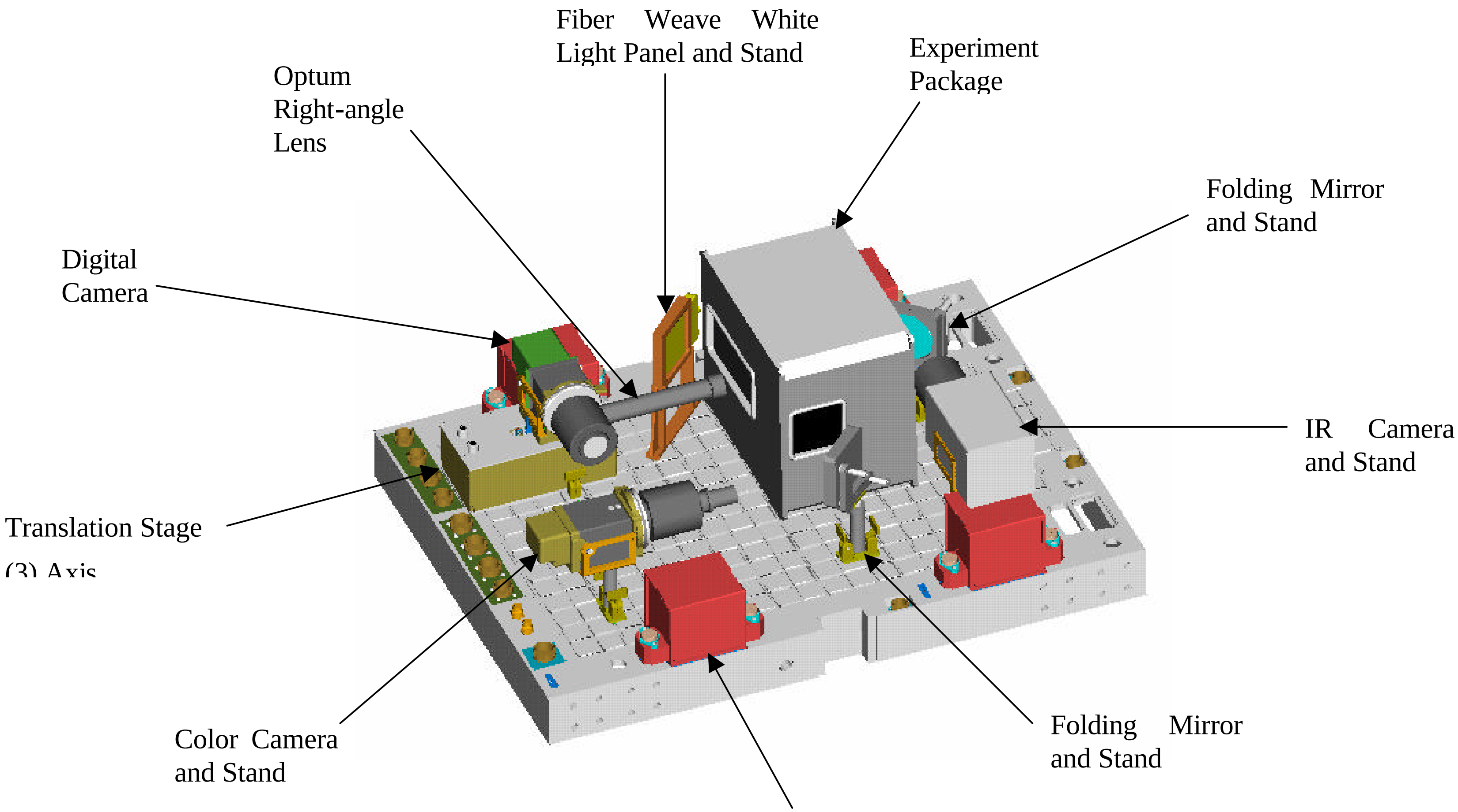
Requirement Types: **Operating Conditions**	**SRD Requirements for f1:** ***Thin Film Fluid Flows at Menisci***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	The EP volume is 21 liters. The test cell is a closed dish that is 10 cm in diameter.	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	Quasi-static < 10^{-3} g if aligned/ 10^{-6} g if unaligned Below 10 HZ isolation from G-jitter frequency Vector alignment: residual vector in "S" direction	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification. PI must orient EP in the rack relative to G vector.
Operating Pressure	1.0 ± 0.1% in the rack	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	20 to 25° C ±0.1°C in the EP	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f1:** ***Thin Film Fluid Flows at Menisci***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Film thickness as a function of distance along wall (from 0 to 15 microns from the wall), normal and axial flow field velocity in the extended meniscus, temperature field in liquid and vapor, shape of the evaporating meniscus.		
Visual Imaging	Framing rate of 30 frame/sec video FOV and Resolution: (1) full interface (10 x 10 cm field of view; resolution to 100 micron) (2) close-up of contact line (~20 x 200 micron image; resolution to 1 micron) Laser for interferometric measurement of film thickness up to 15 microns with resolution of ±0.01 micron Diffuse white background lighting	FIR to provide 2 Hi Resolution B&W cameras and one analog color camera (FCF BSD B.2.3.5.3). FIR to provide cameras and high magnification lens (FCF BSD B2.3.7) *PI to provide lens for microscopy view.* FIR to provide Nd: YAG laser for interferometry (FCF BSD B.2.3.5.4.1.2) FIR to provide white light and white light panel FCF BSD B.2.3.5.4.1.1) through a window on the EP	YES
Temperature field	Temperature distributions at the cell wall and on the film surface are required. Temperature field spatially resolved to ±5 microns.	*PI to provide IR camera, interferometer & lens.*	YES IR camera must interface to RS232 input for control and RS170A for data output.
Velocity field	Velocity of seeded particles as a function of heater power input from 0 to 500 microns/sec ±1%. Particle size assumed to be 5 to 20 microns in diameter for PIV.	*PI to provide specific optics for focusing illumination at different locations (3-D PIV).*	YES PI optics must interface to FIR camera.

Requirement Types: **Systems and Measurements**	**SRD Requirements for f1:** ***Thin Film Fluid Flows at Menisci***	**FCF Capabilities**	**Compliance Comments**
Number, duration of tests	40 tests (4 fluids [pentane, methanol, acetone, F113] at 5 different heat inputs and 2 repetitions); each test run lasting 2 to 3 hours	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f1:** ***Thin Film Fluid Flows at Menisci***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	40 test runs will generate a maximum of 8 TB [64 terabits] of data from the 2 B&W cameras and the analog color camera. Additionally, the IR camera will generate a large amount of data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature measurement and control within the test cell Pressure measurement and control within the test cell	*PI to provide temperature and pressure measurement devices in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Contact Line Hydrodynamics (f2)

Principal Investigator: Garoff

Experiment Objective:

The objective is to measure the flow fields and the interface shapes very close to a dynamic contact line moving at constant velocity in the geometry-independent region.

Experiment Summary:

The test cell will be an open container of liquid with a flat free surface, enforced in microgravity by a pinning surface. There will be a hole in the pinning surface for a rod to be inserted. The free surface can either take on a depressed shape for those cases in which the rod is inserted into the liquid or can come out above the nominal free surface position for those cases in which the rod is pulled out of the container. In either case, the focus is on the area very close to the vicinity of the contact line on the moving rod. It is anticipated that the inner rod must be at least 2 cm in radius and the gap dimensions, defined as the difference between the outer and inner radii, will be variable between 1, 2.5, and 5 cm. The cell depth must be at least 2.5 times the gap dimension. There will be two samples of varying viscosity. A 60000 cSt and a 200 cSt methyl-terminated PDMS.

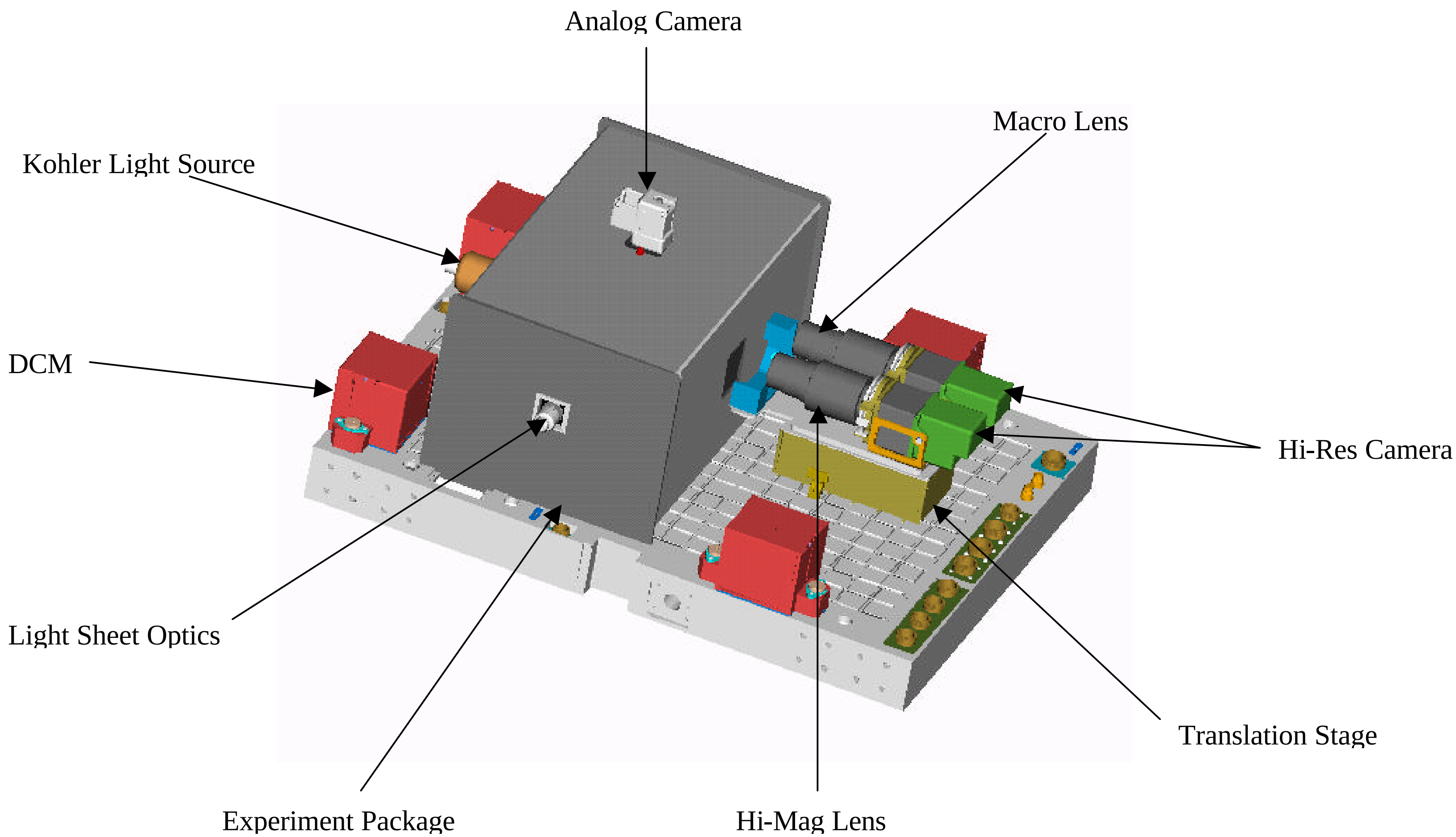
Requirement Types: **Operating Conditions**	**SRD Requirements for f2:** ***Contact Line Hydrodynamics***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	Each EP is 47 liters. There are eight EPs. Total volume is 376 liters.	*PI hardware installed as an integrated package* on the FIR optics plate. NOTE: ISS allocation to FIR estimated at 65 to 90 liters per EP (FCF BSD B.3.1); volume exceeds estimated allocation.	YES – see attached ProE drawing developed from the layout exercise in July/August 2000 for 1 of the 8 EPs NOTE: f2 will require a Double Middeck Locker (Koehler attachment prohibits using a single locker) for each EP.
Acceleration and Vibration	$G/G_0 < 10^{-4}$ for G-jitter frequencies < 10 HZ $G/G_0 < 10^{-4}$ for DC G-levels	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification. PI must orient EP in the rack relative to G vector.
Operating Pressure	1.0 atmosphere ± 1 psi; no control	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	20 to 25° C ±3°C in the EP uniformity to ±2°C for high viscosity fluid uniformity to ±0.1°C for low viscosity fluid	*PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations

Requirement Types: **Operating Conditions**	**SRD Requirements for f2:** ***Contact Line Hydrodynamics***	**FCF Capabilities**	**Compliance Comments**
Other Experiment Conditions	Humidity controlled to less than 6% relative humidity Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	Humidity: FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide humidity measurement and control in the test cell.* *Air flow control – PI to provide air flow control in the test cell*	YES

Requirement Types: Operating Conditions	SRD Requirements for f2: *Contact Line Hydrodynamics*	FCF Capabilities	Compliance Comments
Phenomenon of interest	Flow fields and the interface shapes very close a dynamic contact line moving at constant velocity.		
Visual Imaging	Height (thickness) of the fluid interfaces as a function of position to ± a few microns. Framing rate of 30 frame/sec for transient data and 1 frame/sec for steady state imaging. Resolution of 2 to 3 microns. FOV: (1) 2x2 mm within 5 microns of contact line (2) 1 to 5 cm gap view (3) up to 15 cm for the entire cell	FIR to provide 1 Hi Resolution B&W cameras for position resolution and one analog color camera for surveillance (FCF BSD B.2.3.5.3). *PI to provide Koehler illumination for microscopy.* *PI to provide a beam splitter to get 2x2 mm microscopic view and 1-5 cm macroscopic view*	YES
Particle velocity field	PIV measurements of velocity within 5 microns of the contact line to an accuracy of 2% of the rod velocity. PIV measurements will be done by a digital B&W video camera, with laser sheet generator for illumination. Fluid and particle speeds from 3 to 1,000 microns/sec. Particle sizes from 1 to 5 microns	FIR to provide 1 Hi Resolution B&W cameras for PIV (FCF BSD B.2.3.5.3). FIR to provide Nd: YAG laser for laser sheet (FCF BSD B.2.3.5.4.1.2) FIR to provide white light panel through a window on the EP (FCF BSD B.2.3.5.4.1.1).	YES
Number, duration of tests	1 test consists of observing 1 tube descend into a fluid. Each EP contains 9 tubes and there are a total of 8 EPs (4 for high viscosity fluid and 4 for low viscosity fluid). Therefore there are a total of 72 tests. Each test runs for approximately 2 minutes. Therefore, the duration of all f2 tests is ~144 minutes < 3 hours (excluding set-up time).	*PI to provide 8 Eps.*	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f2:** ***Contact Line Hydrodynamics***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	72 tests collecting images on the 2 B&W and the 1 color camera for 1 minute at 30 fps (dynamic) and 1 minute at 2 fps (steady state) will generate over 4 terabits (513 gigabytes) of data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature measurement and control within the test cell Pressure measurement and control within the test cell	*PI to provide temperature measurement and control in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	“Real time “	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Rheology of Non-Newtonian Fluids (f3)

Principal Investigator: McKinley

Experiment Objective:

The objective is to measure the uniaxial extensional viscosity of a visco-elastic polymer.

Experiment Summary:

To measure uniaxial extensional viscosity of a “Bolgar fluid”, the experimental package (EP) needs to generate a smooth, stable, cylindrical bridge, which will impose a constant strain rate (which can be varied) on the fluid element. The EP must minimize shear stresses (esp. near the end points) and it should be designed to provide a total Henky strain of at least 5. A device is being designed and built for sounding rocket testing. It employs an RDD (radius reduction device), which simultaneously reduces the column radius at the precise required profile, while the column is being stretched exponentially in time. Initial column diameter is 3 cm and the initial column length is 0.3 cm. Final column length is 44 cm. The overall length of an experiment section of the sounding rocket design (sans the avionics) is about 126 cm (50 in.) with a diameter of about 56 cm (22 in.). The experiment as configured in the sounding rocket is too large and heavy for the FIR. It is assumed that a scaled down version maybe possible, although it may restrict the science. It is also assumed that the fluid will be injected into the radius reduction device (RRD), and that the RRD and the fluid injection assembly will be changed out by the crew between each run. It is further assumed that the supporting structure required for the Space Station experiment will be considerably less than that used in the sounding rocket.

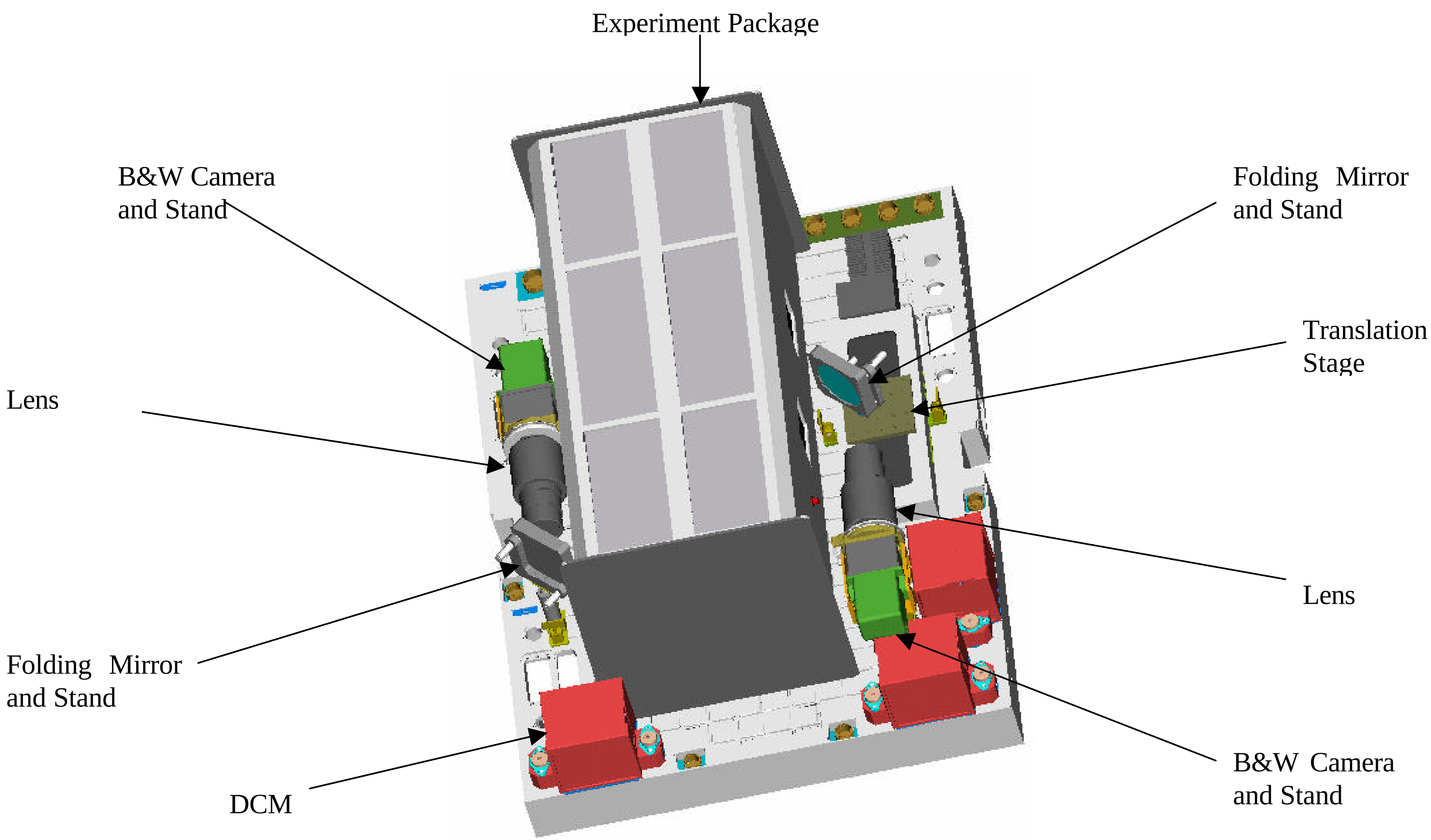
Requirement Types: **Operating Conditions**	**SRD Requirements for f3:** ***Rheology of Non-Newtonian Fluids***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	The EP volume is 356 liters (diameter = 61 cm; length = 122 cm).	*PI hardware installed as an integrated package* on the FIR optics plate. NOTE: ISS allocation to FIR estimated at 65 to 90 liters per EP (FCF BSD B.3.1); volume exceeds estimated allocation.	YES – see attached ProE drawing developed from the layout exercise in July/August 2000
Acceleration and Vibration	$G/G_0 < 0.018$ for DC G-levels $G/G_0 < 0.018$ for G-jitter frequencies < 5 HZ $G/G_0 < 0.03$ for G-jitter frequencies > 5 HZ	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification. PI must orient EP in the rack relative to G vector.
Operating Pressure	1.0 atmosphere ± 1 psi; no control	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	20 to 26° C ±0.1°C all tests at the same temperature ±0.2°C	*PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system.	*PI to provide air flow control in the test cell.*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f3:** ***Rheology of Non-Newtonian Fluids***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	View of exponentially stretching fluid column including focus on column behavior near contact areas. Also, strain rates on the fluid.		
Visual Imaging	Column View: • FOV = 50x50mm; • Resolution = 30-50 microns; • Frame Rate = 30 – 100fps; • Exposure = 1millisec; • Duration = up to 150 sec. Contact Area View: • FOV = 5cm x 5cm; • Resolution = 30-50microns; • Frame Rate = 30 – 100fps; • Exposure = 1millisec; • Duration = up to 150 sec.	FIR to provide Hi Resolution B&W cameras (FCF BSD B.2.3.5.3).	YES
Visual Imaging	Bi-refringence Wave length: TBD Power: 10mW		NO
Particle velocity field	PIV measurements of velocity will be done by a digital B&W video camera, laser (Wave length: Blue-green Power density: .2mW/mm^3), and laser sheet generator (< 300 microns) for illumination. Expect to use silver coated polystyrene spheres of 50 microns diameter. Expect to use 3400 particles per ml of fluid. Fluid (and particle) speeds from 0.2 to 150 cm/s ±0.01cm/s.	FIR to provide Hi Resolution B&W cameras for PIV (FCF BSD B.2.3.5.3). FIR to provide Nd: YAG laser for laser sheet (FCF BSD B.2.3.5.4.1.2) FIR to provide white light panel through a window on the EP (FCF BSD B.2.3.5.4.1.1).	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f3:** ***Rheology of Non-Newtonian Fluids***	**FCF Capabilities**	**Compliance Comments**
Number, duration of tests	10 test runs consisting; each test run 3 minutes (excluding set-up time). Fluids used are monodisperse polystyrene in oligomeric polystyrene oil mixture (non-Newtonian) and oligomeric polystyrene oil (Newtonian)	*PI to provide RDD and fluid injection units for each of 10 runs.* *PI to provide glovebox for sample preparation.*	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f3:** ***Rheology of Non-Newtonian Fluids***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	42 GB of imaging data from 10 runs, assuming 512 x 512 resolutions (binning).	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES
Data acquisition function (non-imaging)	Temperature measurement and control within the test cell at 4 Hz. Measurement of axial force needed to stretch the fluid (as a function of time) in the range from 1 to 10,000 dynes and from 100 to 1,000,000 dynes. Measurement rate at 100 Hz with an accuracy of about +/- 10 dynes.	*PI to provide temperature measurement and control in the test cell.* *PI to provide transducers for measurement of axial force.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	“Real time “ – at average downlink speed of 3 Mbps, 3.1 hours will be required to downlink 4.2 GB of imaging data.	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

Proposed diagnostics layout



Science Requirements Document Summary for

Dynamics of Hard Sphere Colloids (f4)

Principal Investigator: Chakin

Experiment Objective:

These experiments will be studying nucleation, growth, and rheological properties of a hard sphere colloidal suspension. More specifically, the experiments will measure kinetic and equilibrium structures for suspension at various volume fractions to identify the various liquids, crystal, and glass states and their transition regions. Two types of hard sphere experiments are described here. One is an extension to Phase 1, (Cafe experiment) which is on a macro-scale and involves separate test cells for each run, 2.0 cm ID by 1.0 cm long or 3.14 cc. From 8 to 12 test cells (runs) are desired. The other is Phase 2, which is on a micro-scale and involves 200 samples all on one test cell, 10 x 10 x 0.1 cm or 10 liters.

Experiment Summary:

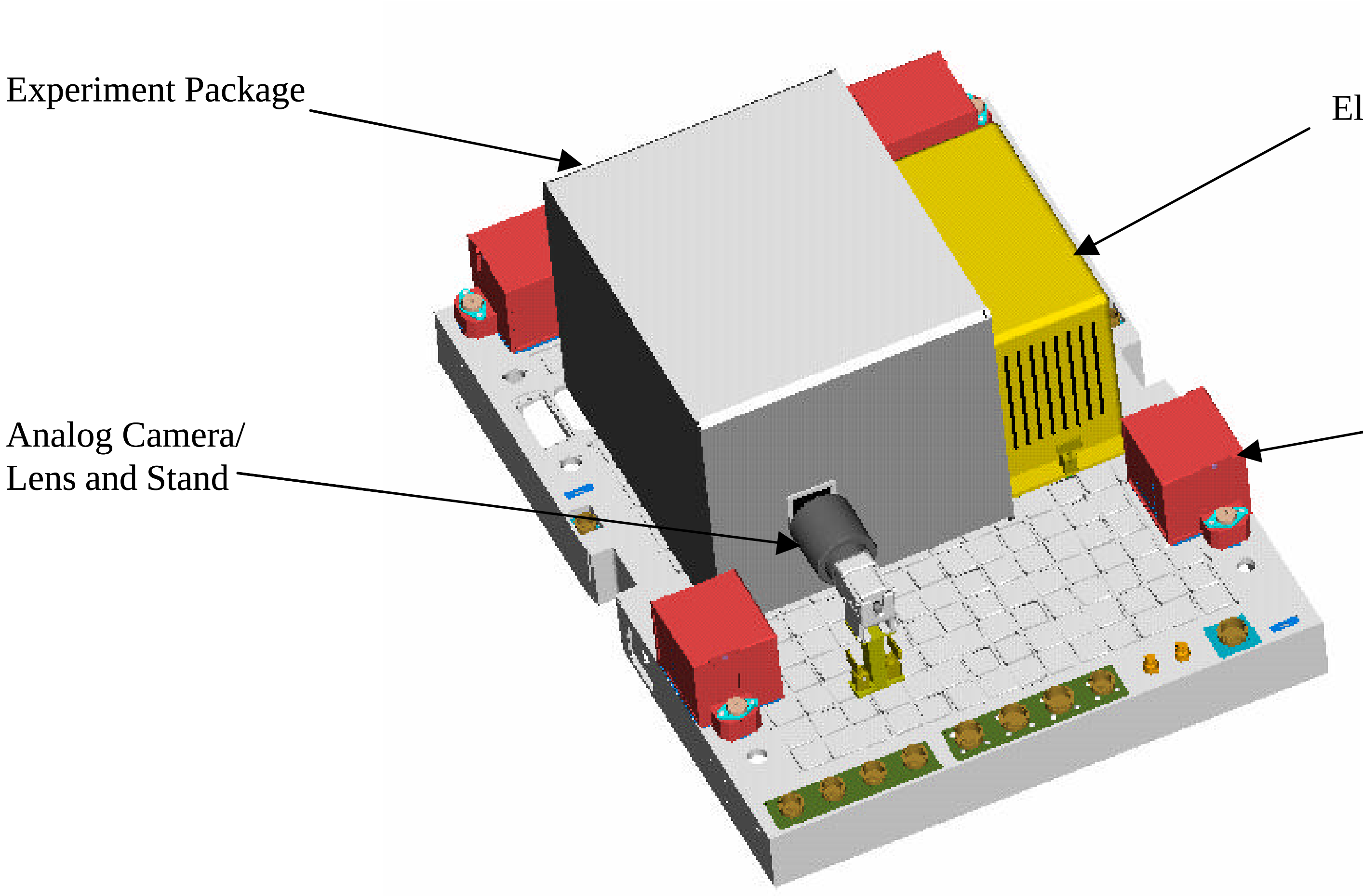
There are two types of hard sphere experiments; one type of experiment involves separate test cells. There will be 8 to 12 cells that are 20 mm ID and 10 mm long. They are completely filled and can accommodate slight changes in volume due to expansion. The other type of experiment is on a micro-scale and involves 200 samples all on one test cell, 10 x 10 x 0.1 cm or 10 liters. In both types, measurements will be made using Bragg, static, and dynamic light scattering techniques.

Requirement Types: **Operating Conditions**	**SRD Requirements for f4:** ***Dynamics of Hard Sphere Colloids***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	The volume of each sample test cell for the Phase 1 extension experiment is 3.14 cc (37.7 cc for 12 test cells). For the Phase 2 experiments, the volume of the single test cell is 10 cubic centimeters. Total volume is 79.5 liters.	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.* NOTE: ISS allocation to FIR estimated at 65 to 90 liters per EP (FCF BSD B.3.1).	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-3}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	Ambient; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f4:** ***Dynamics of Hard Sphere Colloids***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Bragg scattering images and color images of the entire cell.		
Visual Imaging	Framing rate from 2 to 20 frame/sec video FOV 10 X 20 mm Resolution 10 to 50 microns Kohler illumination (collimated white light) Laser: • wavelength 532 nm • power > 30 mW • stability ±0.1% • variable beam diameter from 100 microns to 10mm	FIR to provide 2 Hi Resolution B&W cameras and one analog color camera (FCF BSD B.2.3.5.3). FIR to provide cameras and high magnification lens (FCF BSD B2.3.7) FIR to provide Nd: YAG laser for laser sheet (FCF BSD B.2.3.5.4.1.2) FIR to provide white light and white light panel through a window on the EP FCF BSD B.2.3.5.4.1.1). *PI to provide collimator*	YES
Number, duration of tests	About 30 tests; each test lasting from 4 hours to 10 days (average of 24 hr/test). Fluids used are PMMA with decalin and tetralin.	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f4:** ***Dynamics of Hard Sphere Colloids***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Twelve experiments of 24-hour duration (assuming imaging for 1 min/hour) generate 108 GB of data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature measurements every 10 minutes to ±0.1 °C Oscillation (<50 Hz max) and rotation (1 rps) of the sample	*PI to provide temperature measurement and control in the test cell.* *PI to provide oscillation and rotation devices and associated measurement and control in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

Proposed diagnostics layout



Science Requirements Document Summary for

Colloids Physics (f5)

Principal Investigator: Weitz

Experiment Objective:

The objective of these experiments is to study nucleation, growth, coarsening of crystal structures as well as rheological structural properties of binary alloys (highly ordered) and fractal aggregates (highly disordered structures). For binary alloys, the area of interest is structures, nucleation, growth, and coarsening, and the phase diagrams. For fractal aggregates, the area of interest is large scale invariant structures and their visco-elastic mechanical properties.

Experiment Summary:

There are numerous colloidal samples for these experiments. There will be 8 to 12 cells that are 20 mm ID and 10 mm long. They are completely filled and can accommodate slight changes in volume due to expansion. Measurements will be made using Bragg, static, and dynamic light scattering techniques. Cells design should accommodate oscillations at 0.1 to 50 Hz and rotation at a minimum of 1rps for shear melting.

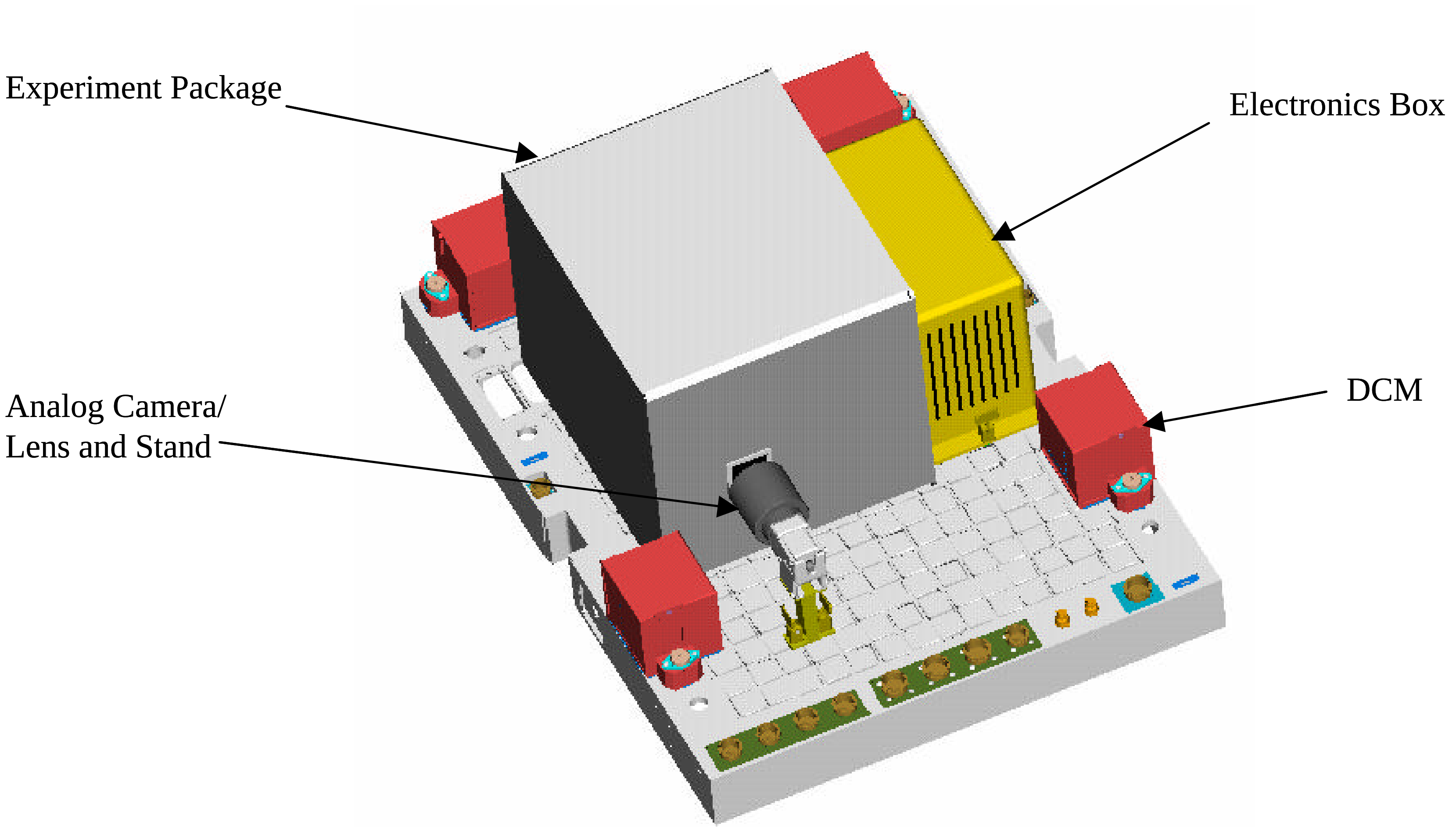
Requirement Types: **Operating Conditions**	**SRD Requirements for f5:** ***Colloids Physics***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	The volume of each sample test cell is 3.14 cc; 37.7 cc for 12 test cells.	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-3}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	Ambient; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f5:** ***Colloids Physics***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Bragg scattering images and color images of the entire cell.		
Visual Imaging	Framing rate single frame video or still camera; images once per hour FOV 10 X 20 mm Resolution 25 to 50 microns Kohler illumination (collimated white light) Laser: • wavelength 532 nm • power > 30 mW • stability ±0.1% • variable beam diameter from 0.1 to 10mm	FIR to provide 2 Hi Resolution B&W cameras and one analog color camera (FCF BSD B.2.3.5.3). FIR to provide cameras and high magnification lens (FCF BSD B2.3.7) FIR to provide Nd: YAG laser for laser sheet (FCF BSD B.2.3.5.4.1.2) FIR to provide white light panel through a window on the EP (FCF BSD B.2.3.5.4.1.1).	YES
Number, duration of tests	About 25 to 100 tests; each test lasting from 1 hours to 5 days (average of 24 hr/test). Fluids used are decalin, tetralin, PS + silica + gold particles, PMMA, PMMA-silica, PMMA + metals.	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f5:** ***Colloids Physics***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Twelve experiments of 24-hour duration (assuming imaging for 1 min/hour) generate 108 GB of data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature measurements every 10 minutes to ±0.1 °C Oscillation (2 to 15 Hz max) and rotation (1 rps) of the sample	*PI to provide temperature measurement and control in the test cell.* *PI to provide oscillation and rotation devices and associated measurement and control in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f5:** ***Colloids Physics***	**FCF Capabilities**	**Compliance Comments**
Up/Down link	“Real time “	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Studies in Electohydrodynamics (f6)

Principal Investigator: Saville

Experiment Objective:

The objective of this experiment is to study liquid bridge instabilities of a cylinder in microgravity. Specifically studying the cylindrical shape, shape dynamics, and pinch off characteristics. These studies will be done on cylinders whose L/D ratios are greater than pi (about 3.14) and are subjected to strong electric fields. Instabilities normally occur for cylinders whose L/D ratios are greater than pi (with no electric field). Such fields are required to stabilize cylinders whose ratios are greater than pi.

Experiment Summary:

A fluid column is held between two plates (electrodes) that produce an electric field between them. This electric field acts as a stabilizing force for otherwise unstable cylinders (L/D ratio greater than pi). The test container can be design such that there are several fluid cells housed within the device (three for the case of BDPU, two test containers, six cells altogether). There are three decoupled systems altogether linking linear drive motor volumes, test cells, and electric control subsystems. Only one cell is run at a time. The overall size of the test container is 22 x 41 x 25 cm. Each test cell assembly has the ability to deploy a fluid cylinder via an injection mechanism to a given L/D ratio and to apply the appropriate electric field. Liquid cylinders are 5 mm diameter and can range from 1 to 5 cm in length. Of the three test cells one was a two fluid system and the other two cells were single fluid. It is expected that the two fluid cell will have to be filled prior to orbit. In addition, other features of the cell assemblies were fluid compensators for thermal expansion, fluid injection/extraction systems, and high voltage spherical contacts.

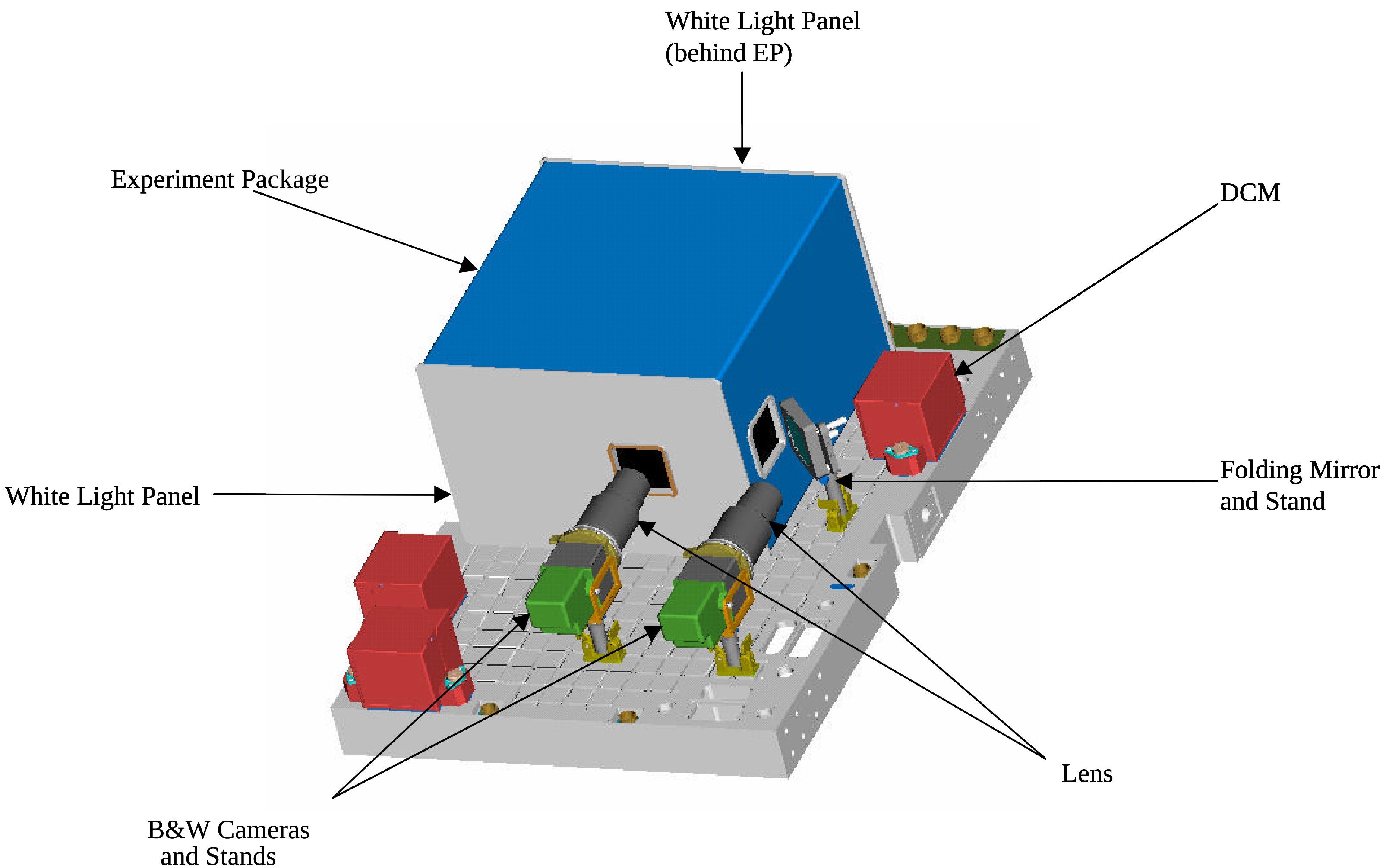
Requirement Types: **Operating Conditions**	**SRD Requirements for f6:** ***Studies in Electohydrodynamics***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	Overall test container is about 20X40X25 cm = 20 liters	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-5}$ for DC G-levels for 45 minutes $G/G_0 < 10^{-4}$ for DC G-levels for 60 minutes for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	20 to 25° C ±0.5°C in the EP for each test	*PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f6:** ***Studies in Electohydrodynamics***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	View of the entire cylinder containing the fluid column; two orthogonal views.		
Visual Imaging	Framing rate: • 30 fps generally • 100 to 500 fps for detailed pinchoff phenomena FOV: • 5 to 10 cm for overall cylinder • About 1 mm for detailed pinchoff phenomena Resolution 100 microns for overall view	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3) FIR to provide 1 ultra-high frame rate camera (FCF BSD B.2.3.5.3.1.3) FIR to provide white light and white light panel through a window on the EP (FCF BSD B.2.3.5.4.1.1).	YES
Voltage	Voltage measurement from 0 to 20,000 volts controlled to ±5% (0-5 kV/cm and 0-500 Hz AC). Capability to measure very small currents	*PI to provide voltage step-up*	YES
Number, duration of tests	About 80 tests; each test lasting 15 to 30 minutes. Fluids used are mineral oil, castor oil, silicone oil, water, SF_6.	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f6:** ***Studies in Electohydrodynamics***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Each test will generate as much as 120 GB [~ 0.9 tera bits] of imaging data (assuming 2 B&W cameras at 30 fps for 20 minutes and high rate camera at 500 fps for 10 seconds). Therefore, 80 tests will generate as much as 9.6 TB [~76 tera bits].	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature measurements ±0.1 °C at a frequency of 1 Hz. Voltage measurement from 0 to 20,000 volts controlled to ±1% accuracy, measure with a frequency of 10 Hz. Current - Capability to measure very small (micro to nano amps) currents controlled to ±1% accuracy, measure with a frequency of 10 Hz..	*PI to provide temperature measurement and control in the test cell.* *PI to provide voltage and current measuring devices* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f6:** ***Studies in Electohydrodynamics***	**FCF Capabilities**	**Compliance Comments**
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Nucleation and Growth of Microporous Crystals (f7)

Principal Investigator: Dutta

Experiment Objective:

The objective of this experiment is to study the crystal growth characteristics of microporous materials and correlate definitive molecular growth events with observed crystal growth behavior. Specifically want to use “reverse miscellar” chemistry to grow these structures and want to look at three types of growth scenarios: 1) layer-by-layer type of growth; 2) Sigmoid type of growth; and 3) solid state reconstruction type of growth.

Experiment Summary:

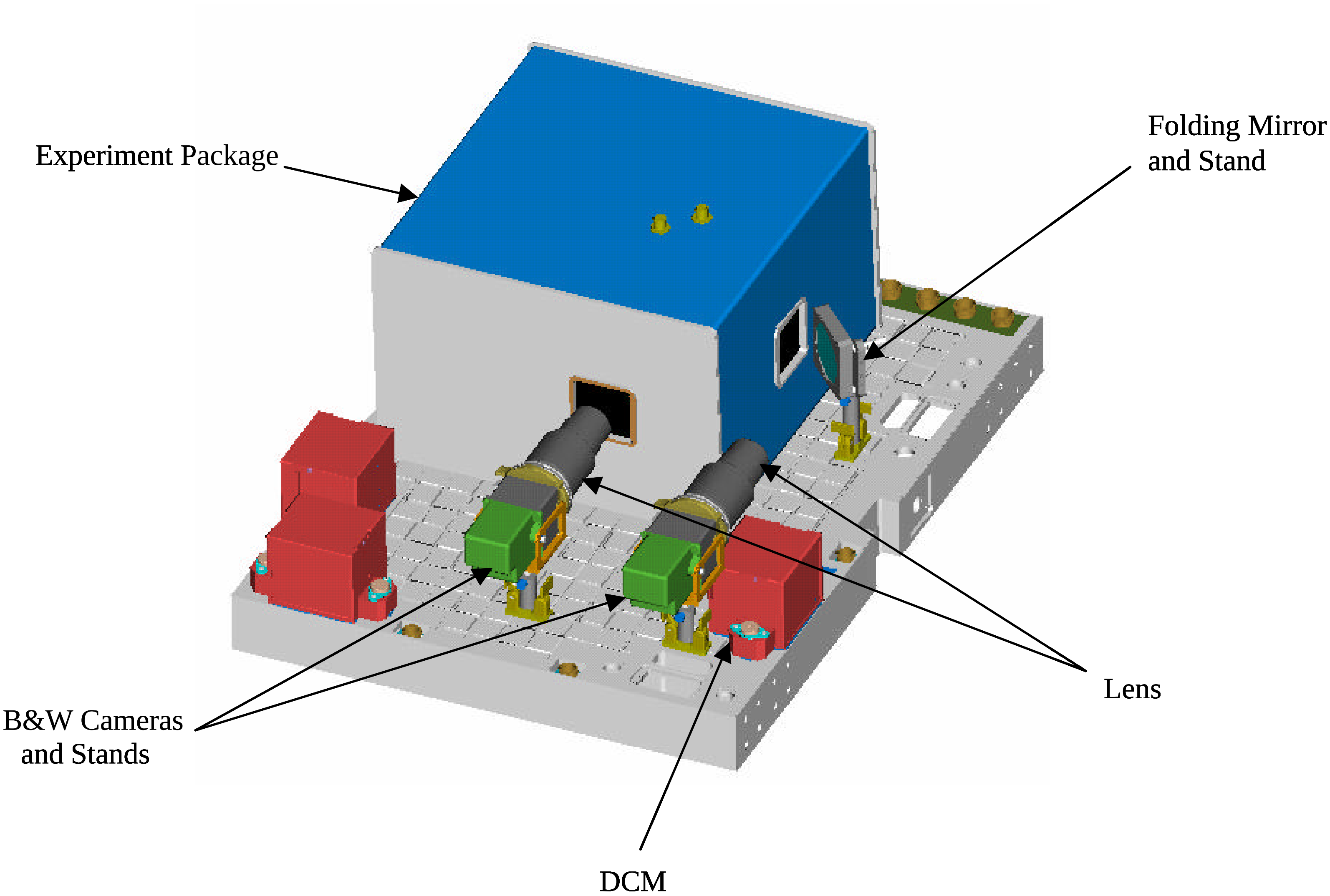
Generally this experiment is the ON-ORBIT mixing of two reactants and the subsequent study of the resulting crystal growth size of the period of many days. The crystals grow into what is called zeolite-type microporous structures. Actual zeolite microporous structures, which typically use Al of Si as their structural material, have ubiquitous uses in many industrial chemical processes (e.g., production of gasoline). The proposed experiments here will achieve zeolite-type structures using Zn and P as the soluble reactants and will be accomplished using reverse micellar chemistry. The use of reverse miscelles (which are microdroplets of water containing the Zn and/or P reactants is a solution of a surfactant and a hydrocarbon, hexane in this case) is wanted as the miscelles provide a context for timely management of the reactions. The basic process is as follows: prepare a solution of surfactant (AOT) and n-hexane on the ground; prepare aqueous zinc and phospate solutions separately (usually in some base solution); equilibrate 200 ml of the n-hexane solution with 8 ml of the aqueous Zn solution; ditto for the P solution; load containers with 40 or 50 ml of reactants; on-orbit remove separation and mix reactants of all four containers. Periodically take light scattering measurements to ascertain crystal size over several days. Have four containers to investigate three growth modes. The first is a layer-by-layer diffusive type growth mechanism; the second is more of a nuclei aggregation with a rapid uptake process; and the third is a rapid precipitation of amorphous particles (a gel-like substance) followed by a solid state restructuring. The various pathways are achieved by different initial reactant (Zn and P) concentrations in the solutions. Sample test cells are small – on the order of 100 ml. The fourth container will be like the first except that it contains seed particles.

Requirement Types: **Operating Conditions**	**SRD Requirements for f7:** ***Nucleation and Growth of Microporous Crystals***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	The volume of a sample test cell with a single couvette is 100 milliliters or 400 milliliters for 4 test cells (0.4 liters). The dimension of the test cell is 4 x 4 x 8 cm. EP volume is estimated at 21 liters	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-4}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	20 to 25° C ±1°C in the EP for each test	*PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f7:** ***Nucleation and Growth of Microporous Crystals***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	General viewing of crystals at different stages of growth in the cells using B&W images of the entire cell and dynamic light scattering.		
Visual Imaging	Framing rate: 30 fps FOV: 1 X 10 cm depending upon the cell size and the crystal size at the time of observation. Resolution: • 10 microns for visual imaging • 1 – 5,000 nm for light scattering Diode laser: • wavelength 675 nm • power ~ 3 mW Diffuse white lighting for background.	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3). FIR to provide diode laser (FCF BSD B.2.3.5.4.1.3) FIR to provide white light to the EP (FCF BSD B.2.3.5.4.1.1). *PI to provide laser white light panel Optics* *PI to provide lensing for high-magnification*	YES
Number, duration of tests	4 test cells within the EP. Duration of 5 days for Type A, 36 hours for Type B, 2 hours for Type C. Fluids uses are N-hexane, zinc nitrate, sodium hydroxide, phosphoric acid.	*PI to provide the ability to accommodate multiple samples* *PI to provide glovebox for on-orbit mixing of the test cells inside the EP.*	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f7:** ***Nucleation and Growth of Microporous Crystals***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Dynamic light scattering measurements frequency • For type A – every 60 minutes • For type B – every 30 minutes • For type C – every 10 minutes Using conservative assumptions, total data gather will be ~300 GB [2.4 tera bits].	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature measurements ±1 °C with a measurement frequency of 0.01 Hz.	*PI to provide temperature measurement and control in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Interactions of Bubbles and Drops (f8)

Principal Investigator: Subramanian

Experiment Objective:

The objective of this experiment is to study thermocapillary migrations of bubbles and drops in fluids and correlate experiment data (change in interfacial tension as a function of temperature gradient and dynamic viscosity as a function of velocity) with theoretical predictions.

Experiment Summary:

This experiment studies bubbles and drops undergoing thermocapillary migration. This motion results from the surface tension imbalance and the subsequent fluid flow on the bubble interface due to local temperature gradients. Such studies are typically done in a rectangular fluid cell with a constant temperature gradient imposed by temperature-controlled surfaces. The bubbles/drops are injected and their subsequent motion/behavior are studied. Several bubbles/drops may be injected before extraction occurs. Various control parameters include: bubble/drop diameter, single or multiple deployments, temperature gradient, and the fluids combination. It should also be possible, in the case of multiple deployments, to inject bubbles or droplets at various relative orientations with respect to each other.

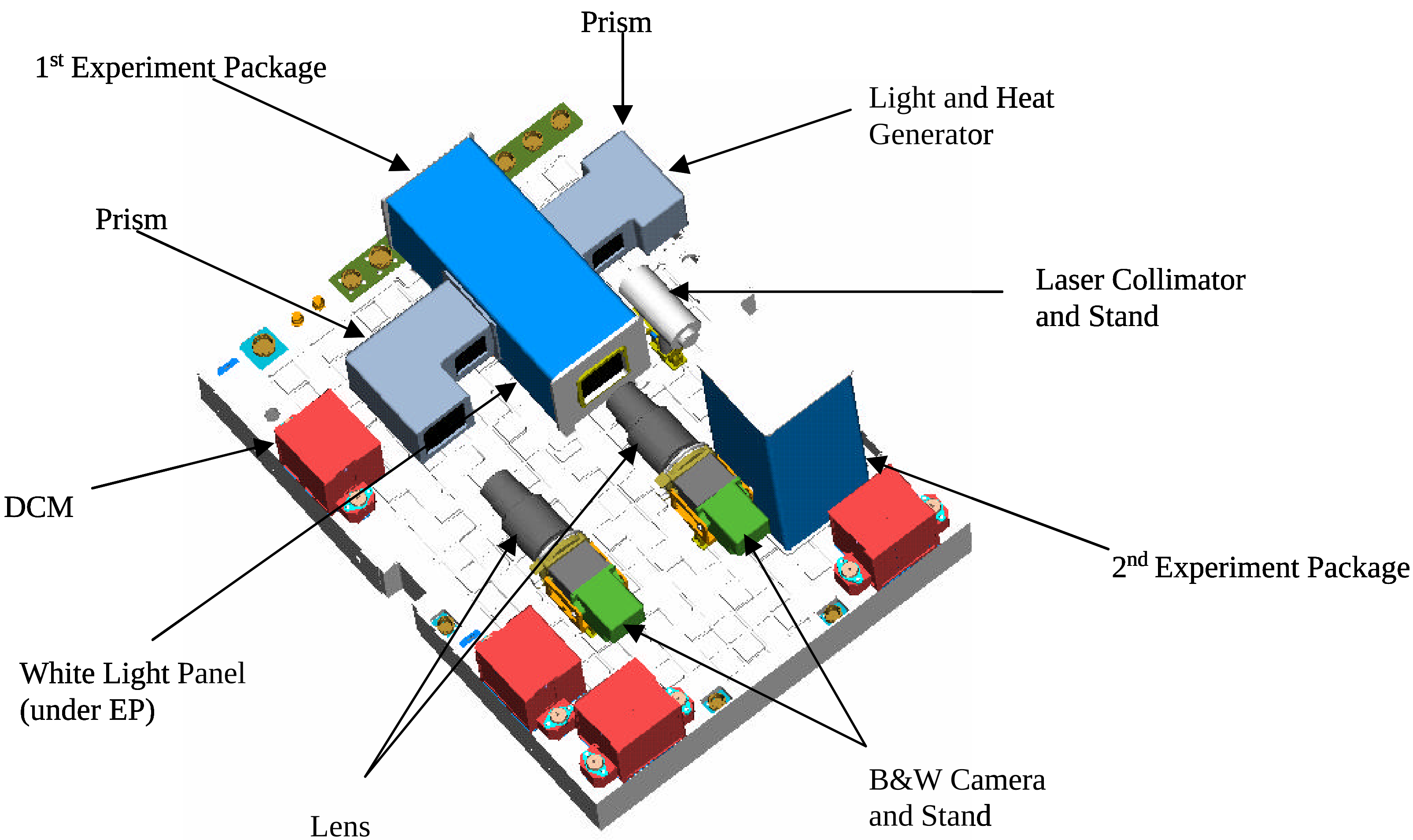
Requirement Types: **Operating Conditions**	**SRD Requirements for f8:** ***Interactions of Bubbles and Drops***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	Test Cell dimensions are 5x5x10 (cm). Two test cells will be used (one for the bubble experiment, another for drops).	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-5}$ for DC G-levels $G/G_0 < 10^{-5}$ for G-jitter frequencies < 0.01 HZ	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere ±5%; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	-20 to +120° C ±1°C with uniform gradient; transverse variations <0.1°C; longitudinal gradient variation <±1°C in the EP.	*PI to provide thermal control of test cell using thermoelectric coolers (Peltier elements) at both ends of the test cell to achieve the desired temperature gradients.*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f8:** ***Interactions of Bubbles and Drops***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	General viewing of test cells with bubbles/drops from two orthogonal views to measure bubble/drop sizes and movement as a function of temperature and viscosity.		
Visual Imaging	Framing rate: 30 fps FOV: • about 5 X 10 cm for viewing the entire cell • 5 times the bubble/drop radius Resolution: 1 – 5% of bubble diameters Laser for white light panel for optics and interferometry Background lighting for two orthogonal views	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3). FIR to provide cameras and high magnification lens (FCF BSD B2.3.7) FIR to provide Nd: YAG laser for white light panel and interferometry (FCF BSD B.2.3.5.4.1.2) FIR to provide diode laser for background lighting (FCF BSD B.2.3.5.4.1.3) FIR to provide white light for background lighting (FCF BSD B.2.3.5.4.1.1). *PI to provide white light panel optics for PIV diagnostics*	YES
Temperature field	Temperature fields measured to about 5 times the bubble radius; spatial resolution of 500 microns.	FIR to provide one analog color camera (FCF BSD B.2.3.5.3). *PI to provide beam splitting and recombination*	
Velocity field	Velocity fields measured in the range from 0.01 to 1.0 cm/s; accuracy ±1%	*PI to provide white light panel optics for PIV diagnostics* *PI to provide reference grid for particle tracking*	

Requirement Types: **Systems and Measurements**	**SRD Requirements for f8:** ***Interactions of Bubbles and Drops***	**FCF Capabilities**	**Compliance Comments**
Number, duration of tests	About 150 tests; each test lasting from 1 –15 minutes (plus 2 hours equilibration time). Fluids uses are silicone oils, FC-75.	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f8:** ***Interactions of Bubbles and Drops***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Using conservative estimates on the amount of data required and assuming 20 minutes of data collection per test and 4 tests per day, total data gather will be ~500 GB/day [~4 tera bits/day].	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	-20 to +120° C ±1°C with uniform gradient; transverse variations <0.1°C; longitudinal gradient variation <±1°C in the EP.	*PI to provide temperature control and measurement devices in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Thermocapillary Motion of Bubbles and Drops (f9)

Principal Investigator: Davis

Experiment Objective:

The objective of this experiment is to study thermocapillary migrations, coalescence, and subsequent phase segregation of bubbles and drops. The migration will be under the action of gravity and/or thermocapillarity. Specific areas of interest include: growth rates of the segregated layer; characteristic times for the total coalescence of the disperse phase; and the study of the relative effects of migration versus coalescence.

Experiment Summary:

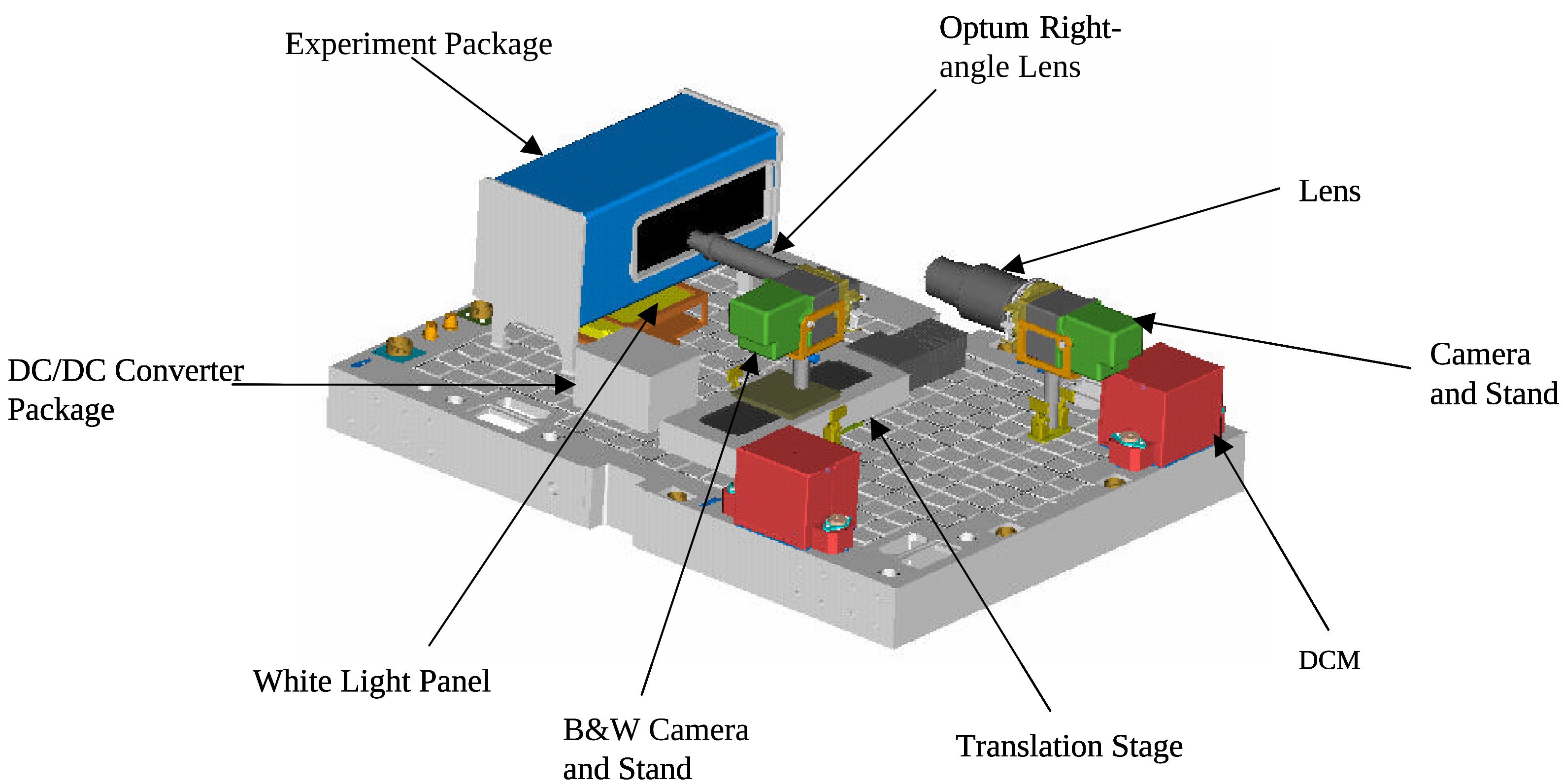
These experiments study a suspension of bubbles migrating toward an interface under the action of gravity and/or thermocapillary effects. The effects of migration and coalescence and phase segregation are to be studied. The measurement of the rate of phase segregation and the imaging of drop coalescence is especially desired near the phase interface. As both thermocapillary and gravitational driven motions are to be studied, vector alignment may be necessary. Want to also observe both the temporal and special droplet distributions throughout the cell. It is envisioned to generate and mix the suspension on-orbit and to load it into the cell. Not only are suspensions to be studied but small population bubbles (i.e., 3-6 bubbles) will be studied for their coalescence and interacting mechanisms.

Requirement Types: **Operating Conditions**	**SRD Requirements for f9:** ***Thermocapillary Motion of Bubbles and Drops***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	Each EP is 18 liters. Total volume for the 2 EPs is 36 liters.	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-3}$ for DC G-levels Vector alignment may be required for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3) *PI to ensure vector alignment*	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere ±1%; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	-20 to +120° C ±1°C with uniform gradient; transverse variations <0.1°C; maximum gradient expected is 3°C in the EP.	*PI to provide thermal control of test cell using thermoelectric coolers (Peltier elements) at both ends of the test cell to achieve the desired temperature gradients.*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f9:** ***Thermocapillary Motion of Bubbles and Drops***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	General viewing of bubbly suspensions throughout the cell and close up views of bubbles near interface.		
Visual Imaging	Framing rate: 30 fps FOV: • 10 X 10 cm for viewing the entire cell • 5 times the radius around interacting bubbles • within 2 cm of coalescence at the interface Resolution: 1 – 5% of bubble diameters Laser for white light panel for optics and interferometry Background lighting	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3). FIR to provide Nd: YAG laser for white light panel and interferometry (FCF BSD B.2.3.5.4.1.2) FIR to provide diode laser (FCF BSD B.2.3.5.4.1.3) and white light panel (FCF BSD B.2.3.5.4.1.1) for background lighting *PI to provide laser white light panel and white light panel optics for PIV diagnostics*	YES
Temperature field	Temperature fields measured to about 5 times the bubble radius; spatial resolution of 500 microns.	FIR to provide one analog color camera (FCF BSD B.2.3.5.3). *PI to provide beam splitting and recombination*	
Velocity field	Velocity fields measured in the range from 0.01 to 1.0 cm/s; accuracy ±1%	*PI to provide laser white light panel and white light panel optics for PIV diagnostics* *PI to provide reference grid for particle tracking*	
Number, duration of tests	About 75 tests; each test lasting from 1 –15 minutes (plus 2 hours equilibration time). Fluids uses are silicone oils, FC-75.	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f9:** ***Thermocapillary Motion of Bubbles and Drops***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Using conservative estimates on the amount of data required and assuming 20 minutes of data collection per test and 4 tests per day, total data gather will be ~500 GB/day [~4 tera bits/day].	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	-20 to +120° C ±1°C with uniform gradient; transverse variations <0.1°C; longitudinal gradient variation <±1°C in the EP.	*PI to provide temperature control and measurement devices in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Interfacial Transport and Micellar Solubilization (f10)

Principal Investigator: Hatton

Experiment Objective:

The objective of this experiment is to study the diffusion of a solute across a surfactant-laden interface. Being done in microgravity, it is possible to study larger diffusion layers in the absence of solutally driven convection. Low surfactant concentrations can delay the interfacial transport of the solutes; whereas formation of micelles or reversed micelles at high surfactant concentrations can mediate the solubilization and interfacial transport processes. The goal is to understand a more fundamental picture of the events occurring at the interface. Specific objectives are: investigating the effects of surfactant type and concentration, solvent type and concentration, solute molecular structure and temperature on interfacial transport processes. A further objective is to study the interfacial transport processes associated with the formation and coalescence of micellar aggregates at the interface between two phases.

Experiment Summary:

As mentioned above, the experiment studies interfacial transport processes across fluid interfaces. It does this by establishing liquid-liquid interfaces, which initially have a concentration jump at the interfaces. Therefore for subsequent times, the diffusion processes continue. Initial conditions are established in a diffusion cell, which is initially separated into two “halves”. The lower half is filled with an aqueous solution; whereas the upper half is filled with an organic solution and a small water layer (about 700 microns thick) at the bottom of the cell half. There are a variety of solutions, solution concentrations, surfactants, and surfactants concentrations, as well as micellar structures that will be studied during the full run of the experiments. The actual experiment begins when the lower cell half is filled with a known concentration of the transferring solute and is brought up to meet the hydrophilic membrane at the bottom of the upper cell half. After the cell halves are contacted, solute begins to diffuse across the membrane, through the water layer, and into the organic phase. Concentration profiles are then measured on both sides of the interface over time (e.g., using interferometry). The presence of the water layer expands the aqueous-organic interface so that it can be optically probed. With the microgravity experiments, want to study adverse density gradient situations that would be problematic in a one-g environment.

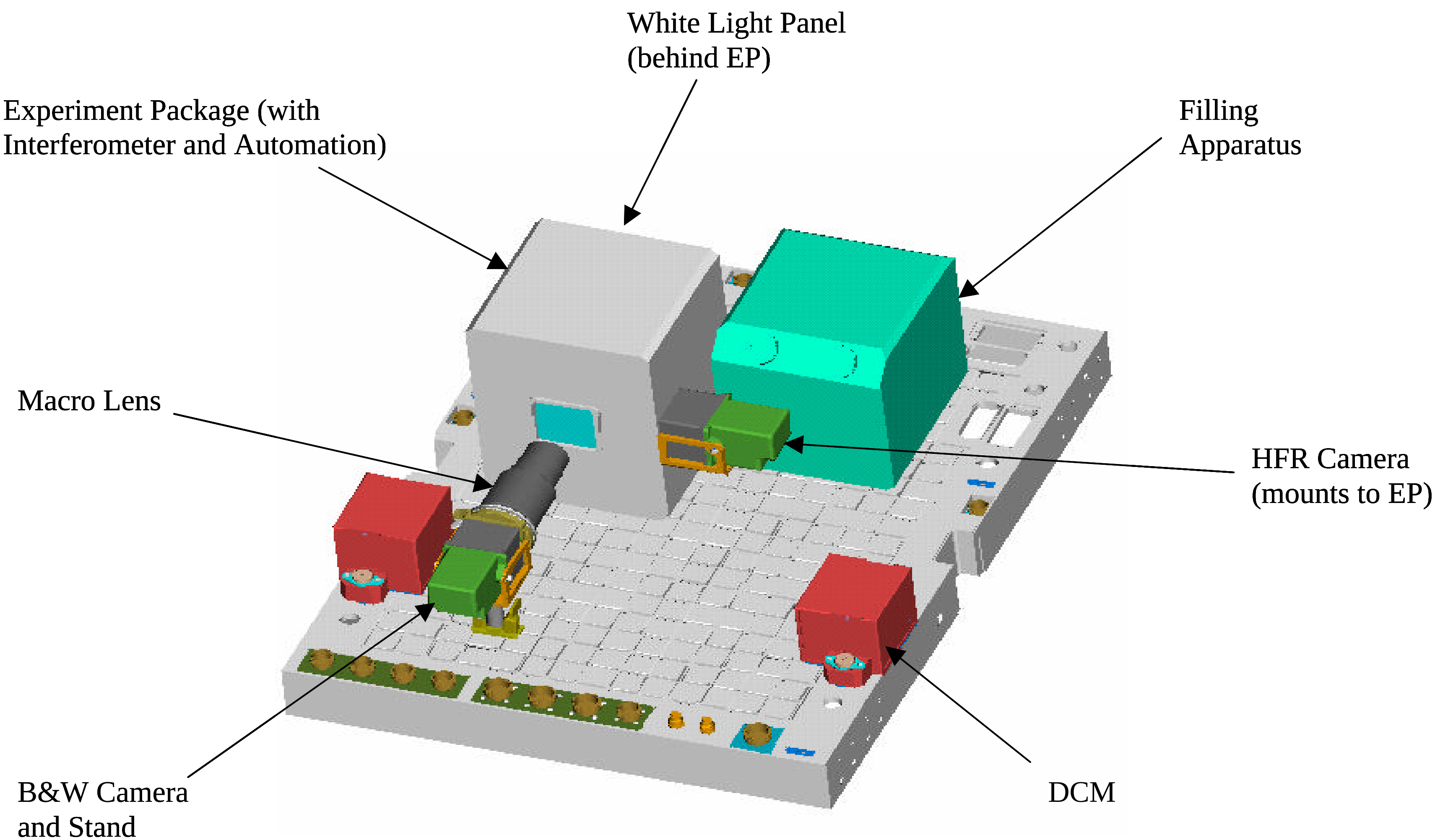
Requirement Types: **Operating Conditions**	**SRD Requirements for f10:** ***Interfacial Transport and Micellar Solubilization***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	The volume of a test cell is 2 x 4 x 1 cm. For 36 test cells, this amounts to 0.29 liters. The EP is 16 liters	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-3}$ for DC G-levels required ($< 10^{-4}$ desired) for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	10 to 35° C ±0.01°C in the EP	*PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f10:** ***Interfacial Transport and Micellar Solubilization***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	General viewing of test cells as well as interferometric images in order to study the diffusion of a solute across a surfactant-laden interface as a function of temperature and concentration for various solutes and organic fluids		
Visual Imaging	Framing rate: • 300 fps for 5 sec (initial transients) • 1 frame (B&W) every 5 minutes • 1 frame (color) every 15 minutes FOV: • 0.25 X 4 cm for viewing the entire cell • 0.25 X 0.5 mm for interferometric view Resolution: • 1 – 5 microns for interferometry • 25 microns for viewing the entire cell Diffuse white background light	FIR to provide Hi Resolution B&W cameras (FCF BSD B.2.3.5.3). FIR to provide one analog color camera (FCF BSD B.2.3.5.3). FIR to provide 1 ultra-high frame rate camera (FCF BSD B.2.3.5.3.1.3) FIR to provide white light for background lighting (FCF BSD B.2.3.5.4.1.1).	YES
Temperature field	Temperature field thermal resolution of ±0.1 °C Temperature field spatially resolution to TBD.	*PI to provide IR camera, interferometer & lens.*	YES IR camera must interface to RS232 input for control and RS170A for data output.
Concentration field	Concentration field concentration resolution of ±5% Concentration field spatially resolution to TBD Laser for white light panel for concentration field diagnostics	FIR to provide Nd: YAG laser for interferometry (FCF BSD B.2.3.5.4.1.2)	YES – assumes concentration field measured using interferometry

Requirement Types: **Systems and Measurements**	**SRD Requirements for f10:** ***Interfacial Transport and Micellar Solubilization***	**FCF Capabilities**	**Compliance Comments**
Number, duration of tests	About 50-100 tests; each test lasting from 1-2 hours. Organic fluids uses are toluene, heptane, and ethanol; solute used is methyl nicotonate; surfactant used is AOT or SDS.	*PI to provide the ability to accommodate multiple samples*. *PI to provide glovebox for EP set up*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f10:** ***Interfacial Transport and Micellar Solubilization***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Assuming 36 tests (1 set of measurements per test cell), the experiment generates ~400 MB of data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES
Data acquisition function (non-imaging)	Temperature must be controlled within ±0.01°C in the EP; experimental range is from 10 to 35° C. Temperature will be measured in about 5 locations in the EP; data collected at 1 Hz.	*PI to provide temperature control and measurement devices in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

Proposed diagnostics layout



Science Requirements Document Summary for

Thermocapillary and Double-Diffusive Phenomena (a.k.a. TCCE=Thermocapillary Convection Experiment) (f11A)

Principal Investigator:

Experiment Objective:

The objective of this experiment is to study various phenomena resulting from surface tension variations on a free surface. More specifically, the objective is to study surface flows and how they propagate into the bulk fluid. Surface deformations are also of interest. It is also of interest to determine under what conditions oscillations occur and at what point the flow becomes turbulant.

Experiment Summary:

The thermocapillary motion of fluid in a cell is engendered by surface tension forces as imposed by temperature gradients parallel to the fluid interfaces. It is assumed that the fluid interfaces are flat (with a 90 degree contact angle). It is expected that the effect of surface flows will penetrate deeper into the bulk in a low-gravity environment. Various temperature gradients, container shapes and dimensions, and various fluids and surfactants will be used. Flows here are unconditionally unstable. The experiment is to study the various flow patterns and measure the surface temperature fields. It is expected that the flows can range from 2-D flows to 3-D flows exhibiting significant free surface deformation. There may even be situations for which oscillatory circumferential flows exist (for the cylindrical case).

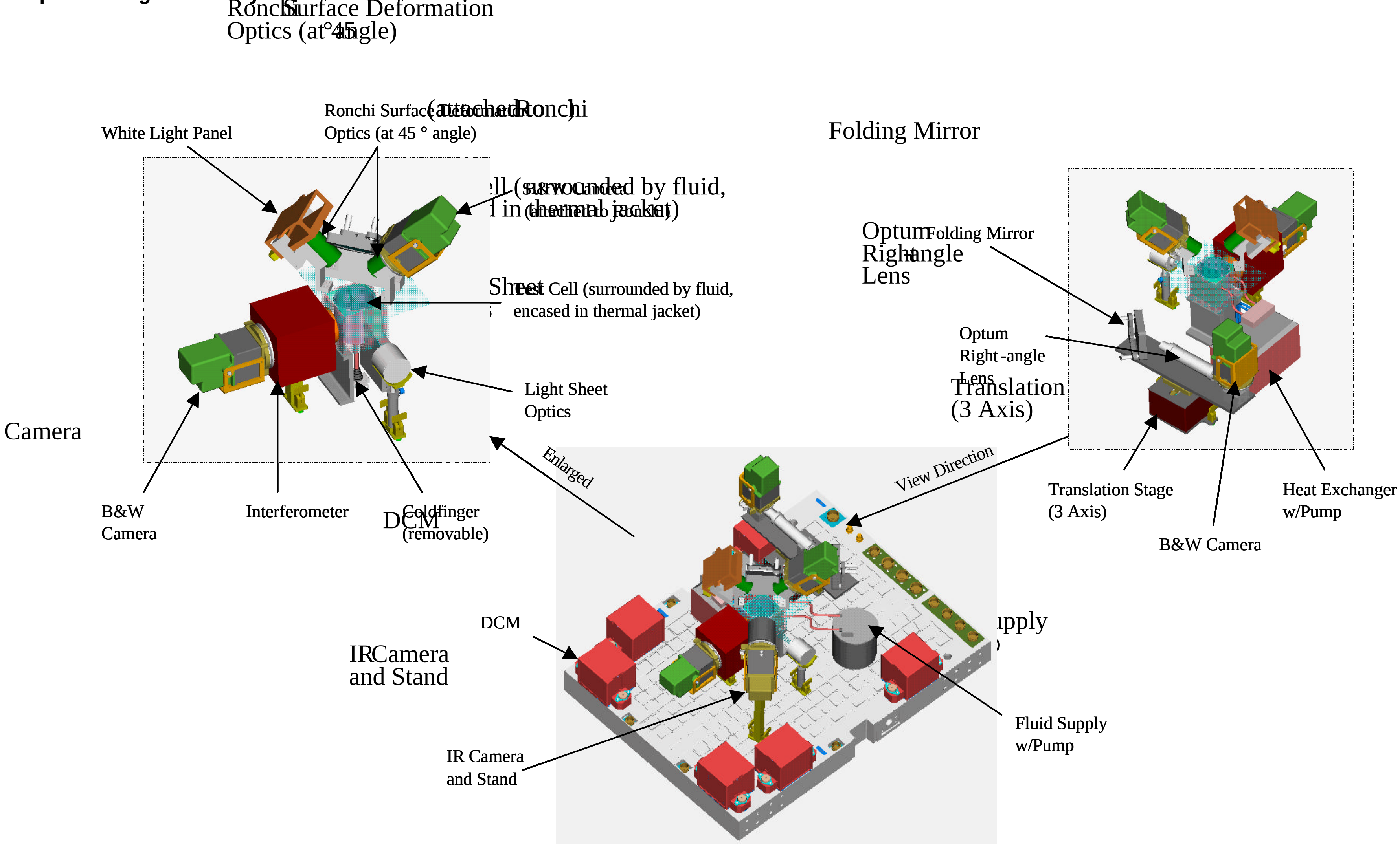
Requirement Types: **Operating Conditions**	**SRD Requirements for f11A:** ***Thermocapillary and Double-Diffusive Phenomena (a.k.a. TCCE=Thermocapillary Convection Experiment)***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	24 test cells. EP volume is 21.5 liters.	*PI hardware installed as an integrated package on the* FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-4}$ for DC G-levels required for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	Conditions in the EP range from 0 to 100°C; controlled to ±0.5°C; measured to ±0.1°C	*PI to provide thermal control within EP*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in test cell* *PI to provide glovebox for EP set up.*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f11A:** ***Thermocapillary and Double-Diffusive Phenomena (a.k.a. TCCE=Thermocapillary Convection Experiment)***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Velocity field, temperature field, and concentration field		
Visual Imaging	Framing rate: 30 to 100 fps FOV: • 10 X 10 cm for viewing the entire cell • 1 x 1 cm to 2 X 2 cm for detail viewing Resolution: • 100 microns for 10 x 10 cm area • 10 microns for detail viewing	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3). FIR to provide 1analog color camera (FCF BSD B.2.3.5.3). FIR to provide 1ultra-high frame rate camera (FCF BSD B.2.3.5.3.1.3) FIR to provide white light for background lighting (FCF BSD B.2.3.5.4.1.1).	YES
Position field	Measure surface deformations; resolution ±50 to 100 microns.	*PI to provide Ronchi Surface Deformation Optics and interface to B&W camera.*	YES
Temperature field	Temperature field measurements at the fluid surface (both perpendicular and parallel to the free surface) and in the bulk fluid; thermal resolution of ±0.1 °C required; spatial resolution TBD required.	*PI to provide IR camera, interferometer & lens.*	YES -- IR camera must interface to RS232 input for control; RS170A for data output
Velocity field	Velocity field measurements desired both parallel and perpendicular to the free surface Expected velocities from 0 to 20 cm/sec; required resolution is 1% at higher velocities and 10% at lower Particle size 50 to 70 microns in diameter for PIV	FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) *PI to provide sheet generator, which interfaces to laser.*	YES
Concentration field	Required resolution is ±5%	FIR to provide diode laser (FCF BSD B.2.3.5.4.1.3)	YES – assumes concentration field measured using interferometry

Requirement Types: **Systems and Measurements**	**SRD Requirements for f11A:** ***Thermocapillary and Double-Diffusive Phenomena (a.k.a. TCCE=Thermocapillary Convection Experiment)***	**FCF Capabilities**	**Compliance Comments**
Number, duration of tests	About 50 tests; each test lasting from 1-2 hours. Fluids used silicone oils, glycerol, water, aqueous solutions of copper sulphate with sulfuric acid.	*PI to provide accommodation of multiple samples*. *PI to provide glovebox for EP set up*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f11A:** ***Thermocapillary and Double-Diffusive Phenomena (a.k.a. TCCE=Thermocapillary Convection Experiment)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Estimated total data collected for this basis experiment ~3 TB [~24 tera bits] excluding the IR data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature controlled within ±0.5°C in the EP; experimental range is from 0 to 100° C. Data collected at 1 Hz at the cell wall and at 10 Hz internal to the test fluid.	*PI to provide temperature control and measurement devices in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Induced Instability (a.k.a. IIE = Induced Instabilities Experiment) (f11B)

Principal Investigator:

Experiment Objective:

The objective of this experiment is to study various phenomena that result from a temperature gradient applied across a fluid interface. More specifically, the experiment is to verify that Benard type fluid motion exists in microgravity; to characterize the critical Marangoni numbers, and to investigate high Marangoni number convection patterns. Of particular importance is to be able to verify that such instabilities are surface-tension driven and not gravity-driven. Unlike TCCE, these temperatures gradients are applied perpendicular -- not parallel -- to the fluid interface. Specifically want to study the cellular type of flow that results (Benard cells, single or multiple layers).

Experiment Summary:

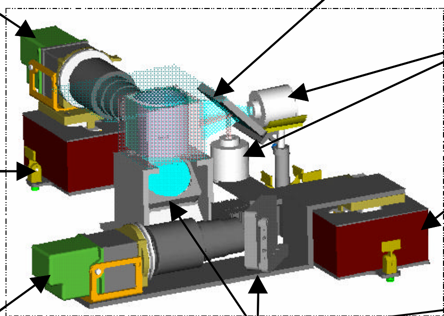
As with TCCE, this experiment uses a cell with a flat free surface. However, unlike TCCE, the temperature gradients for IIE are perpendicular to the flat free surface. The flows are completely of a differenct character; and are conditionally unstable. Below certain Marangoni numbers (on the order of 80) there is no flow or slow concentric roll waves. Above the critical Ma number there is the classically hexagonal flows. At Ma numbers much above 80, the fluid may exhibit oscillatory mode transfer. The interfaces for these experiments could be liquid-liquid or gas-liquid. It is important that the free surface remain flat (with a 90 degree contact angle). Parameters in the experiments include temperature gradients, various container shapes and aspect ratios, various fluid combinations, and perhaps even variable fluid depth. Want to study the various flow patterns; measure the temperature fields both perpendicular and parallel to the free surface; and estimate if possible the velocity fields -- again both parallel and perpendicular to the free surface.

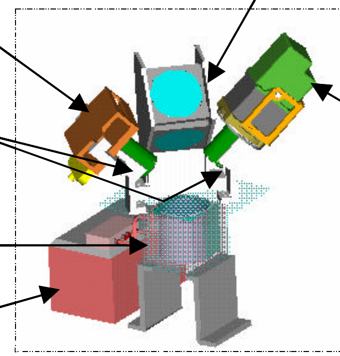
Requirement Types: **Operating Conditions**	**SRD Requirements for f11B:** ***Induced Instability (a.k.a. IIE = Induced Instabilities Experiment)***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	24 test cells. EP volume is 21.5 liters.	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-6}$ for DC G-levels required unless aligned for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	Conditions in the EP range from 15 to 100°C; controlled to ±0.05°C; measured to ±0.01°C	*PI to provide thermal control within EP*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell* *PI to provide glovebox for EP set up*.	YES

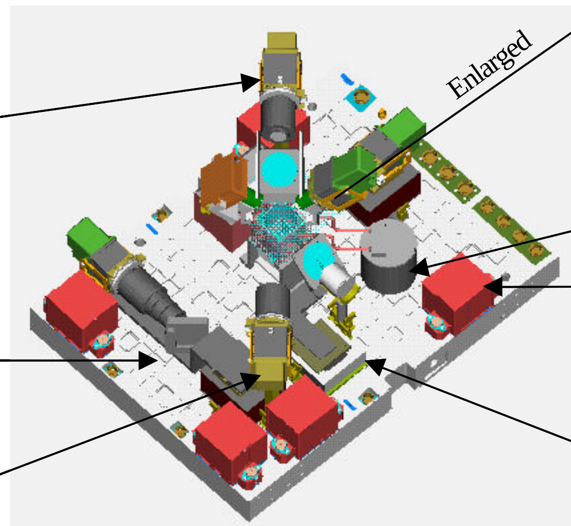
Requirement Types: **Systems and Measurements**	**SRD Requirements for f11B:** ***Induced Instability (a.k.a. IIE = Induced Instabilities Experiment)***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Velocity field, temperature field, and concentration field		
Visual Imaging	Framing rate: 30 to 100 fps FOV: • 10 X 10 cm for viewing the entire cell • 1 x 1 cm to 2 X 2 cm for detail viewing Resolution: • 100 microns for 10 x 10 cm area • 10 microns for detail viewing	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3). FIR to provide 1analog color camera (FCF BSD B.2.3.5.3). FIR to provide 1ultra-high frame rate camera (FCF BSD B.2.3.5.3.1.3) FIR to provide white light for background lighting (FCF BSD B.2.3.5.4.1.1).	YES
Position field	Measure surface deformations; resolution ±50 to 100 microns.	*PI to provide Ronchi Surface Deformation Optics and interface to B&W camera.*	YES
Temperature field	Temperature field measurements at the fluid surface (both perpendicular and parallel to the free surface) and in the bulk fluid; thermal resolution of ±0.1 °C required; spatial resolution TBD required.	*PI to provide IR camera, interferometer & lens.*	YES -- IR camera must interface to RS232 input for control; RS170A for data output
Velocity field	Velocity field measurements desired both parallel and perpendicular to the free surface Expected velocities from 0 to 20 cm/sec; required resolution is 1% at higher velocities and 10% at lower Particle size 50 to 70 microns in diameter for PIV	FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) *PI to provide sheet generator, which interfaces to laser.*	YES
Number, duration of tests	About 50 tests; each test lasting from 1-2 hours. Fluids used silicone oils, glycerol, water, aqueous solutions of copper sulphate with sulfuric acid.	*PI to provide accommodation of multiple samples*. *PI to provide glovebox for EP set up*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f11B:** ***Induced Instability (a.k.a. IIE = Induced Instabilities Experiment)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Estimated total data collected for this basis experiment ~0.5 TB [~4 tera bits] excluding the IR data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature controlled within ±0.05°C in the EP; experimental range is from 15 to 100° C. Data collected at 1 Hz at the cell wall and at 10 Hz internal to the test fluid.	*PI to provide temperature control and measurement devices in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	“Real time “	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout







Science Requirements Document Summary for

Double Diffusion (a.k.a. DDE= Double Diffusion Experiment) (f11C)

Principal Investigator:

Experiment Objective:

The objective of this experiment is to study the flows that are generated by buoyancy due to thermocapillary gradients; or due to the simultaneous presence of temperature and concentration gradients. This latter case is referred to as double diffusive convection. Various modes are possible depending on the orientation of the two gradients to each other as well as to the direction of the gravity vector relative to the cell. One can get flows segregated into various sandwiched layers; or get a fingering sort of phenomena.

Experiment Summary:

Unlike the previous experiments, this fluid cell is completely filled with liquid. There are no free surfaces. Cell geometry would most likely be done in either rectilinear or cylindrical geometries. Rather than studying thermocapillary convection or thermocapillary instabilities, these experiments focus on buoyant convection in a fluid cell. In this experiment, buoyant convection arises from density gradients due to either temperature gradients and/or concentration gradients. Gravity is an explicit factor in these experiments; it is the primary driver for the physics. Its magnitude and direction must be known relative to the cell geometry. It is desired in fact to vary the cells orientation relative to gravity and not only study heating from below (Rayleigh-Benard), but from the sides (Rayleigh), and in between as well. The density gradients will be generated either by temperature gradients or solutal gradients or both. Solutal gradients would be generated by applying a voltage across the electrolyte in the cell; and the thermal gradients would be affected by generating required temperatures on thermally controlled surfaces.

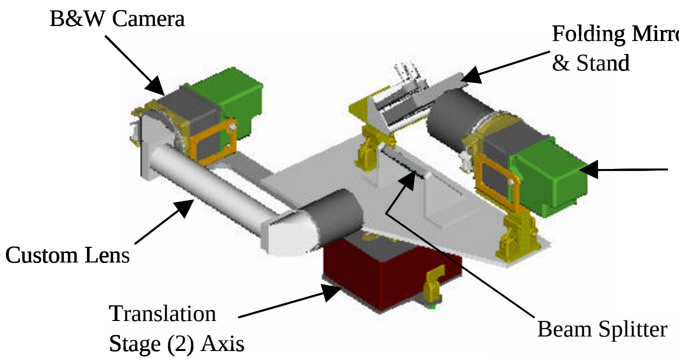
Requirement Types: **Operating Conditions**	**SRD Requirements for f11C:** ***Double Diffusion (a.k.a. DDE= Double Diffusion Experiment)***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	24 test cells. EP volume is 21.5 liters.	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	There are no restrictions on the absolute magnitude of the gravity amplitude. However, it is required that the experiment be able to vary its cell's orientation to the resultant gravity vector with the following angles: +/- 0; +/- 45 deg; and +/- 90 deg. It is required to hold to such angles (to a tolerance of 5 degrees) of orientation for the duration of the experiment run. for G-jitter frequencies – no data	*PI to provide orientation relative to gravity vector*	YES
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	Conditions in the EP range from 0 to 100°C; controlled to ±0.5°C; measured to ±0.1°C	*PI to provide thermal control within EP*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell* *PI to provide glovebox for EP set up.*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f11C:** ***Double Diffusion (a.k.a. DDE= Double Diffusion Experiment)***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Velocity field, temperature field, and concentration field		
Visual Imaging	Framing rate: 1 to 30 fps FOV: • 10 X 10 cm for viewing the entire cell • 1 x 1 cm to 2 X 2 cm for detail viewing Resolution: • 100 microns for 10 x 10 cm area • 10 microns for detail viewing	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3). FIR to provide 1analog color camera (FCF BSD B.2.3.5.3). FIR to provide 1ultra-high frame rate camera (FCF BSD B.2.3.5.3.1.3) FIR to provide white light for background lighting (FCF BSD B.2.3.5.4.1.1).	YES
Position field	Measure surface deformations; resolution ±50 to 100 microns.	*PI to provide Ronchi Surface Deformation Optics and interface to B&W camera.*	YES
Temperature field	Temperature field measurements at the fluid surface (both perpendicular and parallel to the free surface) and in the bulk fluid; thermal resolution of ±0.1 °C required; spatial resolution TBD required.	*PI to provide IR camera, interferometer & lens.*	YES -- IR camera must interface to RS232 input for control; RS170A for data output
Velocity field	Velocity field measurements desired both parallel and perpendicular to the free surface Expected velocities from 0 to 20 cm/sec; required resolution is 1% at higher velocities and 10% at lower Particle size 50 to 70 microns in diameter for PIV	FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) *PI to provide sheet generator, which interfaces to laser.*	YES
Concentration field	Required resolution is ±5%	FIR to provide diode laser (FCF BSD B.2.3.5.4.1.3) *PI to provide interferometer*	YES

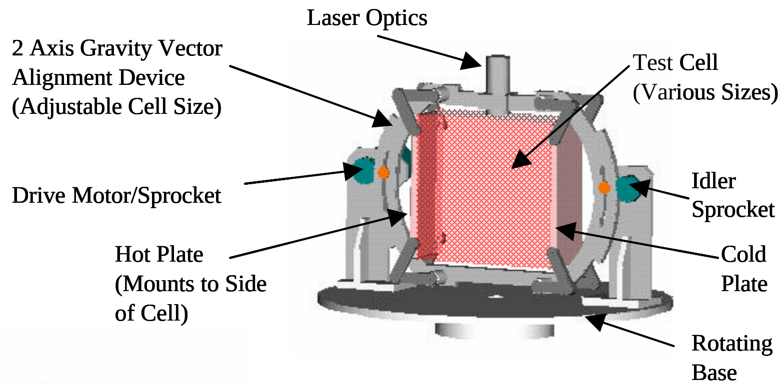
Requirement Types: **Systems and Measurements**	**SRD Requirements for f11C:** ***Double Diffusion (a.k.a. DDE= Double Diffusion Experiment)***	**FCF Capabilities**	**Compliance Comments**
Number, duration of tests	About 50 tests; each test lasting from 1-2 hours. Fluids used silicone oils, glycerol, water, aqueous solutions of copper sulphate with sulfuric acid.	*PI to provide accommodation of multiple samples*. *PI to provide glovebox for EP set up.*	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f11C:** ***Double Diffusion (a.k.a. DDE= Double Diffusion Experiment)***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Estimated total data collected for this basis experiment ~1.5 TB [~12 tera bits] excluding the IR data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature controlled within ±0.5°C in the EP; experimental range is from 0 to 100° C. Data collected at 1 Hz at the cell wall and at 10 Hz internal to the test fluid.	*PI to provide temperature control and measurement devices in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

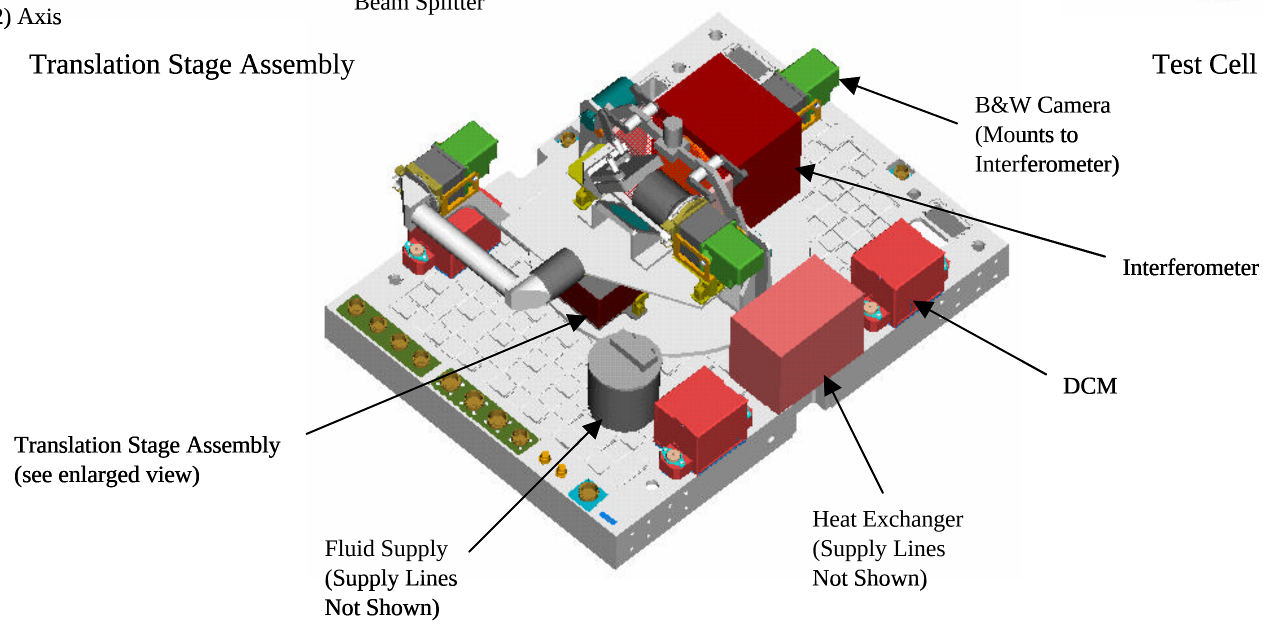
Proposed diagnostics layout



Translation Stage Assembly



Test Cell Assembly



Science Requirements Document Summary for

Critical Point Phenomena (f12)

Principal Investigator:

Experiment Objective:

The objective of these types of experiments is to study equilibrium and non-equilibrium transport and thermodynamic properties very close to the liquid-vapor critical point. There have been numerous experiments in this area in the past. Two have been chosen (TEQB and AFEQ) to be represented in this write-up. They were performed in ESA's CPF (Critical Point Facility). The TEQB (Thermal Equilibrium Bis) studies vanishing behavior of thermal diffusivity near the critical point. The latter experiment AFEQ (Adiabatic Fast Equilibration) studies how pressure-volume work transports energy.

Experiment Summary:

The critical point can be defined as the point on the pressure-temperature-density plot where the quantity {d(rho)/dp} diverges (goes to infinity). That is, the fluid becomes infinitely compressible. Fluids very near the critical point are characterized by an inability to distinguish between a vapor phase and a liquid phase. The critical point exists at a particular pressure, temperature and density -- unique to each fluid. Other fluid properties are also anomalous. For example the following properties diverge (go to infinity) at the critical point: viscosity, specific heat, thermal conductivity, and sound absorption. Some diverge more strongly than others. The thermal diffusivity, however, goes to zero.

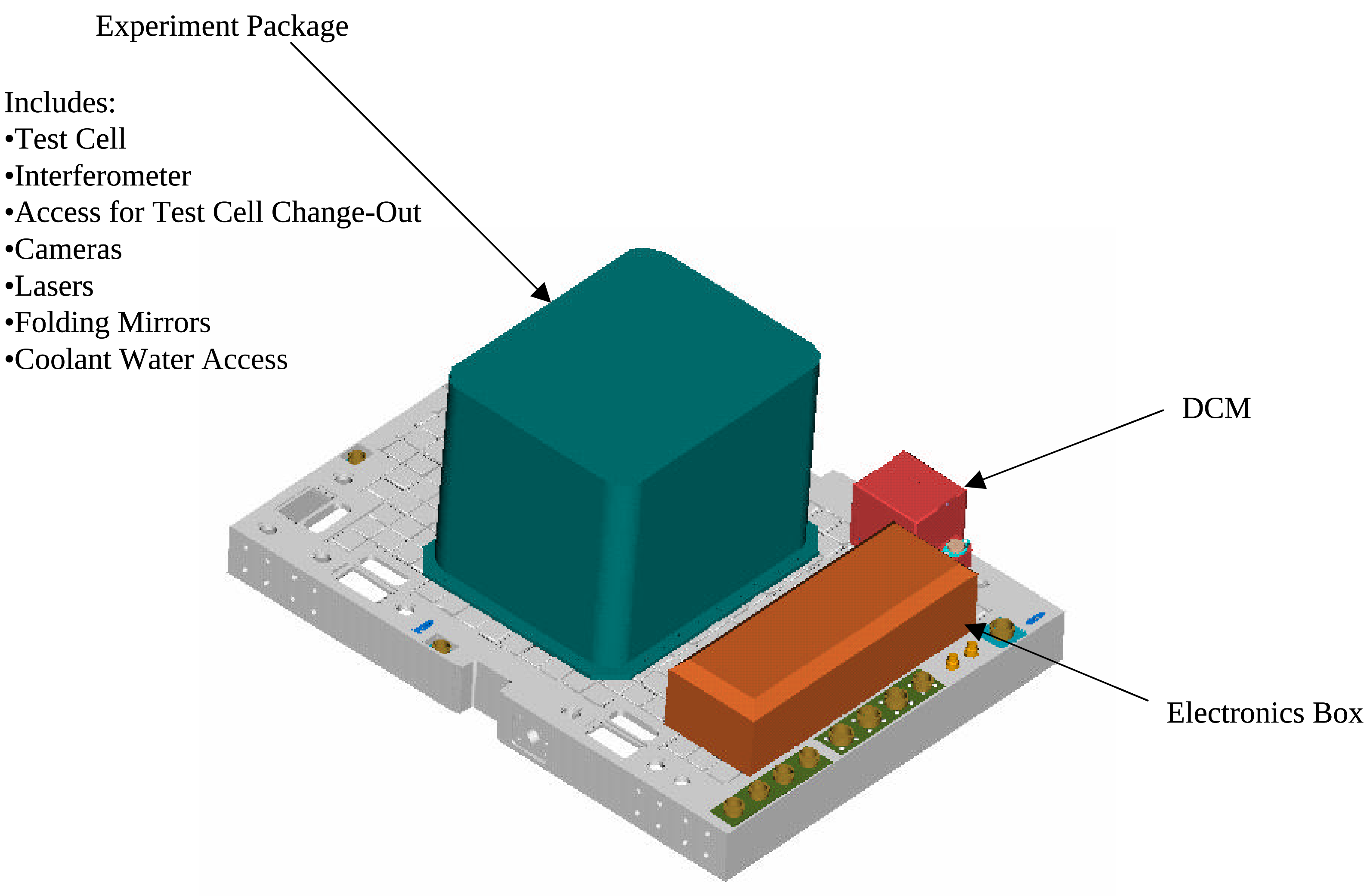
It is because of the diverging compressibility that 1-g experiments are limited. The resultant density stratification in 1-g, produces a zone of fluid very close to critical point conditions that is very small. As gravity goes to zero, this zone widens and facilitates property homogeneity. The divergence of fluid properties occurs very close to the critical point conditions. Therefore the closer you get, the more interesting things become; yet it becomes more difficult to get there. An essential part of these experiments is very precise thermal control; which is realized by the construction of thermostats and control systems. As can be derived from the above discussion, the closer you get to the critical point, the longer it takes to change the fluid temperature (diverging diffusivity). Therefore experiment runs can take many hours or days.

Requirement Types: **Operating Conditions**	**SRD Requirements for f12:** ***Critical Point Phenomena***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	The total volume of all three EPs is 64.5 liters, 21.5 liters each.	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.* NOTE: ISS allocation to FIR estimated at 65 to 90 liters per EP (FCF BSD B.3.1).	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-5}$ for DC G-levels for 30 minutes $G/G_0 < 10^{-3}$ for G-jitter for ALL frequencies	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide measurement of pressure in the EP; no pressure control.*	YES – actively controlled by ISS
Operating Temperature	20 to 25° C ±0.5°C around the EP package	*PI to provide thermal control of test cell.*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide airflow control in EP.* *PI to provide glovebox for EP set up*.	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f12:** ***Critical Point Phenomena***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Direct visualization of fluid		
Visual Imaging	Framing rate: 1 to 200 fps FOV: 12 to 25 mm Resolution: 0.5 to 80 microns	FIR to provide 1analog color camera (FCF BSD B.2.3.5.3). FIR to provide white light for background lighting (FCF BSD B.2.3.5.4.1.1). *PI to provide all other required capability for imaging*	YES
Number, duration of tests	10 to 20 tests; each test lasting from 2 to 20 days. Fluids used xenon, carbon dioxide, and SF_6.	*PI to provide accommodation of multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f12:** ***Critical Point Phenomena***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Total data from a 15 day run is approximately 22 Terabytes. Data is collected throughout the entire run. However, on the shuttle missions that performed a similar experiment, the raw data was not transmitted to the ground. Instead, the raw data was processed in orbit and only processed data was periodically beamed to the ground. This process greatly reduced the amount of data transmitted to a level within present capabilities. Exact protocol TBD.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – Assuming data management protocol similar to that used on shuttle mission that conducted a similar experiment.
Data acquisition function (non-imaging)	Temperature controlled within ±0.5°C in the EP; experimental range is from 0 to 100° C. Data collected at 1 Hz at the cell wall and at 10 Hz internal to the test fluid.	*PI to provide temperature control and measurement devices in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES – Assuming data management protocol similar to that used on shuttle mission that conducted a similar experiment.

Proposed diagnostics layout



Science Requirements Document Summary for

Multiphase Flow Boiling (f13A)

Principal Investigator: McQuillen/Balakotaiah

Experiment Objective:

The field of multiphase flow is defined as the simultaneous flow of liquids (miscible or immiscible) or liquid and vapor (or gas) mixtures in a conduit of some geometry. Generally these flows can be with or without heat transfer. These studies are concerned with flows with no heat transfer. The objectives of these works are to: study bubbly and slug flows, bubble coalescence at low liquid Reynolds numbers, and characterize wavy film behavior for annular flows. More specifically, want to characterize in terms of the parameters of the system, the transitions between flow regimes (i.e., bubbly-to-slug, and slug-to-annular). Also want to characterize pressure gradients for each type of flow regime for a range of flow rates.

Experiment Summary:

On a macro level the experiment will observe how the various phases orient themselves. Typically, in a microgravity environment, this ranges from bubbly flow (at relatively low vapor flow rates), to slug flow, to annular flow (at the relatively high vapor flow rates). It is also of interest to identify and characterize the pressure gradients over a range of flow rates and flow regimes. On a micro level, there are various details of the flow physics that are of interest. For example, in bubbly flow how the bubbles coalesce; in annular flow, the wavy nature of the film; and for slug flow, the thicknesses of the film and geometry of the vapor or liquid slugs. For the flows that do not involve heat transfer, the gas is usually introduced to the liquid flow; i.e., they are mixed together. For liquid vapor flows, they could be mixed as above or the vapor could be generated with heaters. Then, once the two-phase mixture has gone past the diagnostics, the liquid is usually separated and re-cycled into the system. The flows are circulated around the loop via pumps. The controlled parameters of the systems include: liquid flow rates, vapor (gas) flow rates, pipe (or conduit) size, conduit length, and to a smaller degree, temperatures and pressures. Measurements include: pressure drop, perhaps a wall shear stress, void fraction, and imaging. Specific studies of two-phase flows through components such as contractions, expansions, tees, bends, and orifices may be included in the overall effort

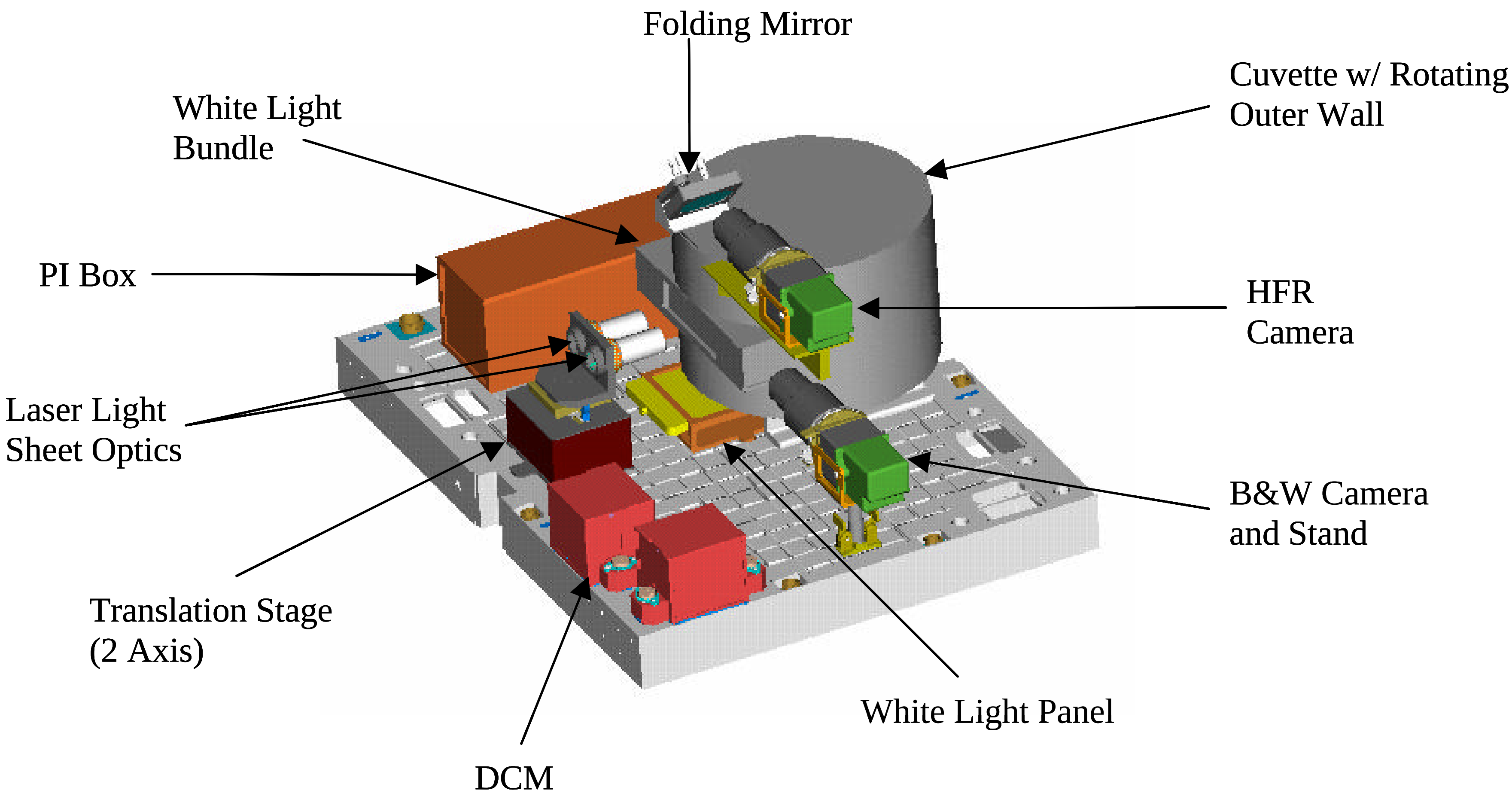
Requirement Types: **Operating Conditions**	**SRD Requirements for f13A:** *Multiphase Flow Boiling*	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	The volume of an EP is 79.5 liters; 238.5 liters for 3 EPs	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.* NOTE: ISS allocation to FIR estimated at 65 to 90 liters per EP (FCF BSD B.3.1).	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-4}$ for DC G-levels Sensitive to G-jitter frequencies < 10 Hz	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required outside EP	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to proved pressure measurement and control in EP*	YES – actively controlled by ISS
Operating Temperature	no control required outside EP	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide thermal control of test cell in EP*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f13A:** *Multiphase Flow Boiling*	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	fluid flow (e.g., flow regimes, pressure drops, void fractions, heat transfer) occurring in two-phased flow in straight cylinders and in tubes with fittings; local fluid phenomena (e.g., bubble velocities and distributions, wave structures); various boiling regimes.		
Visual Imaging	Framing rate: 30 to 1,000 fps (5,000 fps desired) acquired periodically in 30 to 60 seconds durations. FOV: • large FOV from 10 to 30 cm • small FOV about 1 mm Resolution 50 microns (20 microns desired); scale up for larger FOV	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3) FIR to provide 1 ultra-high frame rate camera (FCF BSD B.2.3.5.3.1.3) FIR to provide white light (FCF BSD B.2.3.5.4.1.1).	YES
Velocity field	Expected velocities from 0.05 to 10 m/sec	FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) *PI to provide sheet generator, which interfaces to laser.*	
Number, duration of tests	400 to 500 tests; each test lasting 2 to 10 minutes. Fluids used: liquid mixtures (water+glycerin, water+surfactants, fluorinerts, ammonia); gasses (air, nitrogen, argon, xenon)	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f13A:** *Multiphase Flow Boiling*	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Assuming 1 minute of imaging data for each 10 minute run, each run generates 5.6 GB. The experiment (450 test runs) generates 2.6 TB [~21 tera bits] of data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature measurements in EP ranging from –15 to +200 °C controlled to ±0.5 °C. Pressure measurements in EP ranging from 1 to 10 atmospheres controlled to ±5%.	*PI to provide temperature measurement and control devices in the EP.* *PI to provide pressure measurement and control devices in the EP.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f13A:** *Multiphase Flow Boiling*	**FCF Capabilities**	**Compliance Comments**
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Multiphase Pool Boiling (f13B)

Principal Investigator: Dhir

Experiment Objective:

There are two objectives to this experiment. One is to study nucleate boiling in microgravity and the other is to study boiling mechanisms under low flow conditions. The aim is to develop a basic understanding of heat transfer, vapor removal processes during nucleate boiling and low flow conditions. Specifically, the experiment is to study bubble nucleation, growth and departure; bubble merger and interactions; microlayer evaporation and condensation and the effects of recoil pressure due to phase change and liquid inertia. These will be done with pre-designed cavities. Also want to study the bubble detachment process under flow boiling conditions.

Experiment Summary:

There will be two types of heating surfaces: commercial and ones with prescribed cavity patterns. This will be done at constant surface temperature conditions (NOT constant heat flux). Want to look at bubble nucleation, growth and departure for single and multiple capabilities. Want to test for various subcooling levels, various wall super heats, two kinds of liquids, two kinds of heater surfaces. The number of active sites tested for increases in a systematic manner throughout the tests. Want to conduct tests for various controlled systems pressures, liquid temperatures, heat surface temperatures, flow velocities, and dissolved gas content.

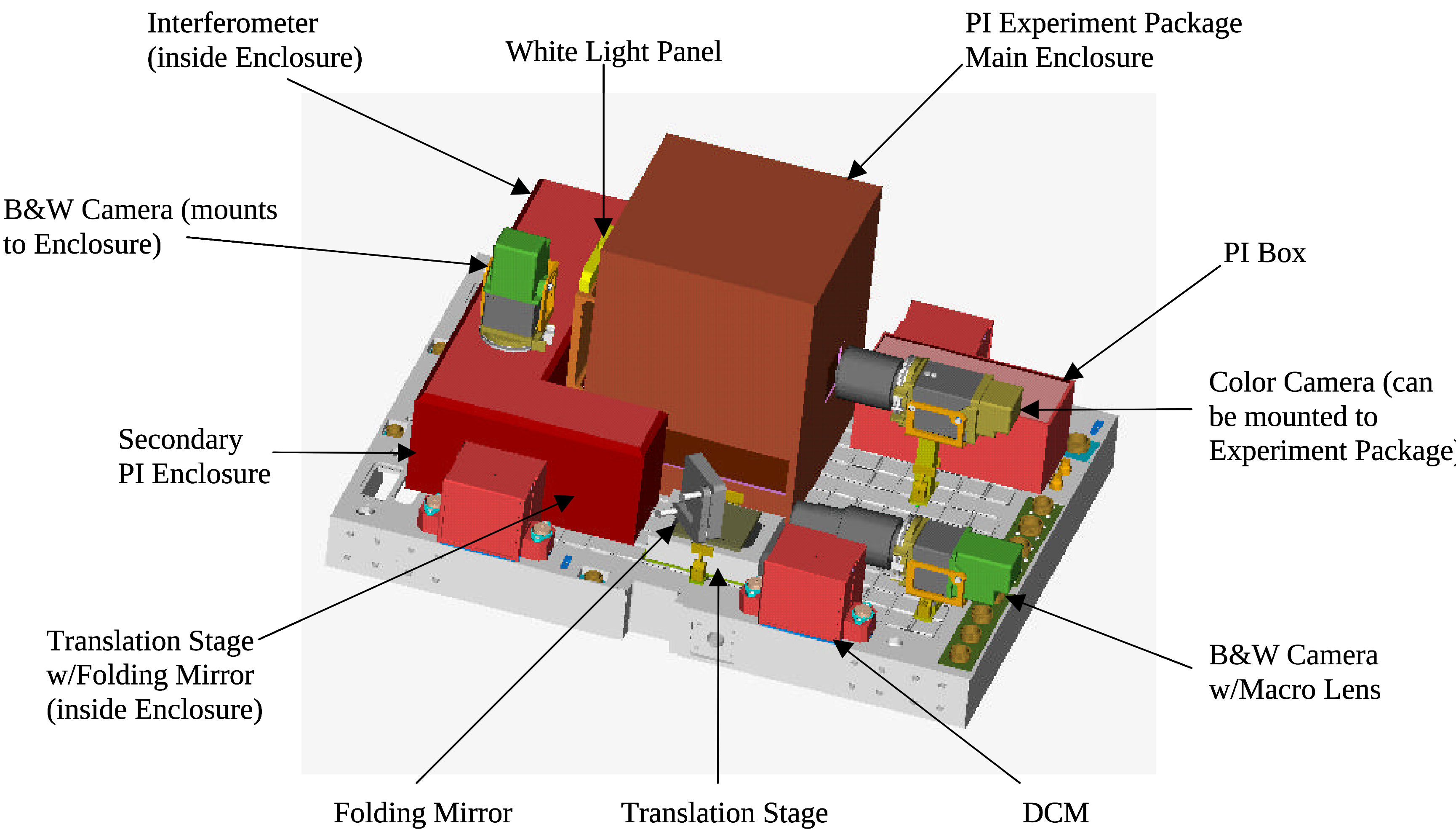
Requirement Types: **Operating Conditions**	**SRD Requirements for f13B:** *Multiphase Pool Boiling*	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	This experiment has 4 separate EP's: • water flow boiling • PF5060 flow boiling • water pool boiling • PF5060 pool boiling Each EP volume is 32 liters X 4 EP's=128 liters.	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.* NOTE: ISS allocation to FIR estimated at 65 to 90 liters per EP (FCF BSD B.3.1); volume exceeds estimated allocation.	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	G/G_0 <2X 10^{-4} for DC G-levels Sensitive to G-jitter frequencies < 10 Hz	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required outside EP	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to proved pressure measurement and control in EP*	YES – actively controlled by ISS
Operating Temperature	no control required outside EP	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide thermal control of test cell in EP*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f13B:** *Multiphase Pool Boiling*	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Bubble nucleation, growth, and departure from a flat heater surface with known nucleation locations		
Visual Imaging	Framing rate: • 10 fps for PF5060 • 5 fps for water FOV: • 12 X 12 cm for PF5060 • 25 X 25 cm for water Resolution: • 150 microns for PF5060 • 250 microns for water Depth of field: • 10 cm for PF5060 • 17 cm for water	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3) FIR to provide white light (FCF BSD B.2.3.5.4.1.1). *PI to provide camera lens for 25X25 cm FOV*	YES
Temperature field	Measure temperature field within 1 cm around bubble	FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) *PI to provide sheet generator, which interfaces to laser.* *PI to provide interferometer.*	YES
Number, duration of tests	50 to 60 tests; each test lasting 15 to 20 minutes after equilibration. Fluids used: PF5060 and water	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f13B:** *Multiphase Pool Boiling*	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Assuming 10 minutes of imaging data for each test times 50 tests generates generates~2 TB [~16 tera bits] of imaging data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature measurements in EP ranging from 59 to 102 °C controlled to ±0.1 °C. Pressure measurements in EP ranging from 110 to 150 kPa measured to ±0.5 kPa.	*PI to provide temperature measurement and control devices in the EP.* *PI to provide pressure measurement and control devices in the EP.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f13B:** *Multiphase Pool Boiling*	**FCF Capabilities**	**Compliance Comments**
Up/Down link	"Real time "	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Proposed diagnostics layout



Science Requirements Document Summary for

Mechanics of Granular Media (f14A)

Principal Investigator: Jenkins

Experiment Objective:

The objective of this experiment is to investigate particle segregation in collisional flows of dry granular materials. This research has experimental, theoretical and simulation components and will focus on the segregation of binary sphere mixtures when spatial gradients in the granular velocity fluctuation energy control the segregation. The experiments will be compared to analytical and numerical calculations. Measured material properties such as densities and collision parameters will be needed for the calculations. The experimental flow consists of fully developed shear flow between parallel boundaries, one of which moves relative to the other.

Experiment Summary:

The cell contains a racetrack-shaped flow chamber with two straight sections joined by two semicircular curved sections. The cell has a moving inner boundary and a fixed outer boundary that imparts the shearing motion to the flow. Appropriately designed bumps, attached to the moving and fixed boundaries, control the energy of the particle velocity fluctuations. The experimental measurements will be derived from video imaging.

Requirement Types: **Operating Conditions**	**SRD Requirements for f14A:** *Mechanics of Granular Media*	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	Total EP volume is 113 liters.	*PI hardware installed as an integrated package on the FIR optics plate.* *PI to provide two levels of containment.* NOTE: ISS allocation to FIR estimated at 65 to 90 liters per EP (FCF BSD B.3.1); volume exceeds estimated allocation.	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 2 \times 10^{-3}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required outside EP EP Pressure between 700 and 1200 mbar measured to 5% accuracy and at 1 Hz	*PI to provide pressure control of test cell and measurement device*	YES – actively controlled by ISS
Operating Temperature	15 to 25° C ±1°C in the EP; measurement frequency of 1 Hz	*PI to provide thermal control of test cell and measurement device.*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations

Requirement Types: **Operating Conditions**	**SRD Requirements for f14A:** *Mechanics of Granular Media*	**FCF Capabilities**	**Compliance Comments**
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system Humidity-- Humidity should be between 50 and 90% and measured to within 5% accuracy at 1 Hz in the test cell	*Air Flow – PI to provide air flow control in the test cell* Humidity: FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide humidity control and measurement device in the test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f14A:** *Mechanics of Granular Media*	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Study motion of spheres through various windows in the side of a “racetrack” cell.		
Visual Imaging	Framing rate: • 30 fps generally • up to 500 fps with smaller FOV FOV: • 20 X 20 cm to 40 X 40 cm Resolution 20 to 60 microns	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3) FIR to provide 1 ultra-high frame rate camera (FCF BSD B.2.3.5.3.1.3) FIR to provide white light and white light panel through a window on the EP (FCF BSD B.2.3.5.4.1.1).	YES
Concentration field	Visual images used to measure relative fraction of small spheres (1.5 to 3.5 mm diameter) from large spheres (1.25 X small sphere diameter) at the sidewalls leads of test cell.	*PI to provide camera lens for 25X25 cm FOV*	YES
Velocity field	Record moving boundary velocity to an accuracy of +/- 1% at 1 Hz. Control to +/- 2%. Sphere velocities are on the order of the moving belt velocity that ranges from 0.25 to 0.6 m/sec.	FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) *PI to provide sheet generator, which interfaces to laser.*	YES

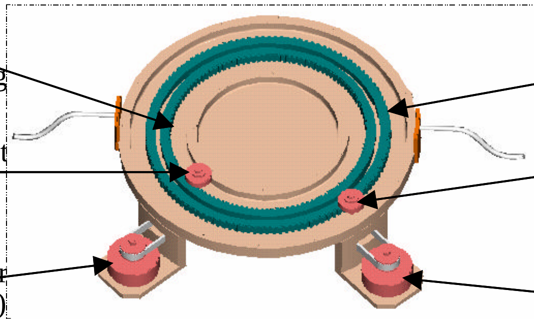
Requirement Types: **Systems and Measurements**	**SRD Requirements for f14A:** *Mechanics of Granular Media*	**FCF Capabilities**	**Compliance Comments**
Number, duration of tests	8 tests; each test lasting 10 to 20 minutes. “Fluids” used are various size metal spheres in air	*PI to provide the ability to accommodate samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f14A:** *Mechanics of Granular Media*	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Each test collects images from: • two 30 fps cameras for ~200 seconds • 10,000 frames from ultra-hi rate camera which will generate ~7 GB/test. Therefore, 8 tests will generate ~56 GB [~0.5 tera bits] of image data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES
Data acquisition function (non-imaging)	Temperature measured to 1% accuracy and a frequency of 1 Hz. Pressure and humidity measured to 5% accuracy and a frequency of 1 Hz.	*PI to provide temperature, pressure and humidity measurement devices in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time " Assuming ISS can download at 3 Mbits/s, time to down-link is 42 hours for all experiment run data.	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

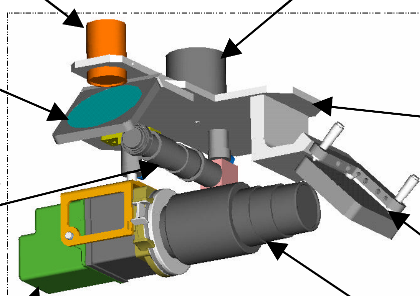
Drive Motor
(Inner Ring)
Drive Motor
(Outer Ring)

Laser
w/Collimator
Drive Motor (mounts
to Gantry Stand)

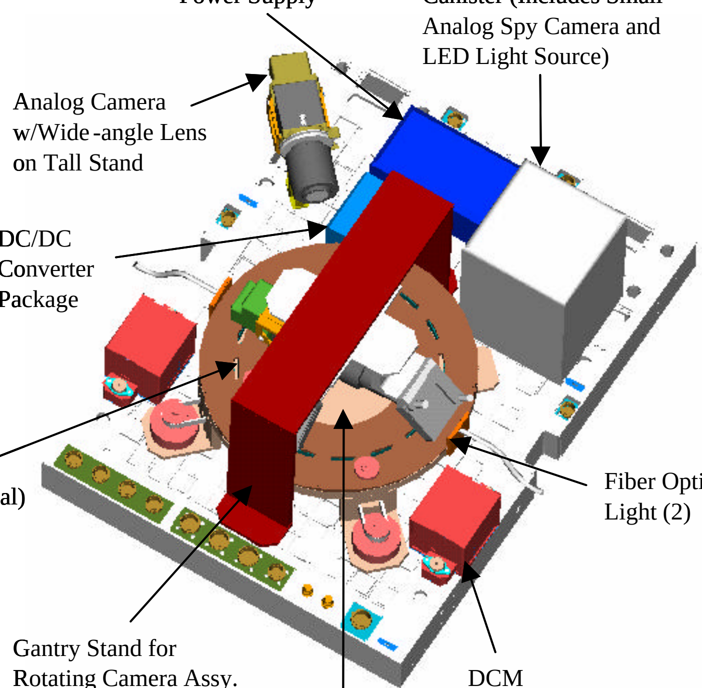
Proposed diagnostics layout



Enlarged View of Rotating Cell
Assy. (Top Cover not shown)



View "A"



See View "A" for
Camera Assembly

*Test Cell Media (Balls) fill gap
between Inner and Outer Drive Ring

Science Requirements Document Summary for

Gas-Particle Interactions (f14B)

Principal Investigator: Louge

Experiment Objective:

Main objective is to study the interaction between a flowing gas with relatively massive particles (constant diameter spheres) that collide with each other and with the moving boundaries of the cell. Over the range of non-turbulent flow conditions, the objectives are to characterize the viscous dissipation of the energy of the particle fluctuations, to measure the influence of particle-phase viscosity on the pressure drop along the cell and to observe the development of localized inhomogeneities likely to be associated with the onset of clusters.

Experiment Summary:

The cell (basically the Jenkins experiment cell) is generally a racktrack-shape design with bumpy frictional boundaries to control the energy of particular fluctuations. Co-current and counter-current gas flows will be introduced through four independent distributors. Measure the particle and gas mean velocities, the fluctuation energy and the particle concentrations in the fully developed regions. Test for various flow and gas properties. The cell has a moving inner boundary and a fixed outer boundary, which imparts the shearing motion to the interior flows. Video imaging, pressure measurement and gas velocity measurement are the necessary diagnostics.

Requirement Types: **Operating Conditions**	**SRD Requirements for f14B:** *Gas-Particle Interactions*	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	Total EP volume is 113 liters.	*PI hardware installed as an integrated package on the FIR optics plate.* *PI to provide two levels of containment.* NOTE: ISS allocation to FIR estimated at 65 to 90 liters per EP (FCF BSD B.3.1); volume exceeds estimated allocation.	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 2 \times 10^{-3}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required outside EP Differential pressures internal to the flow cell will be measured	*PI to provide pressure control of test cell and measurement device*	YES
Operating Temperature	Temperature in the EP should be between 15 and 25 °C and measured to an accuracy of ±1°C at 1 Hz.	*PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system Humidity-- Humidity should be between 50 and 90% and measured to within 5% accuracy at 1 Hz	*Air Flow – PI to provide air flow control in the test cell* Humidity: FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide humidity control and measurement device.*	YES

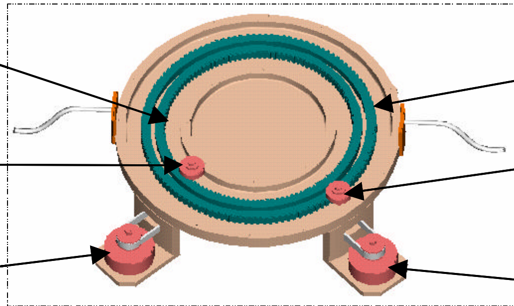
Requirement Types: **Systems and Measurements**	**SRD Requirements for f14B:** *Gas-Particle Interactions*	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Study motion of spheres through various windows in the side of a "racetrack" cell.		
Visual Imaging	Framing rate: • 30 fps generally • up to 500 fps with smaller FOV FOV: • 20 X 20 cm to 40 X 40 cm Resolution 20 to 60 microns	FIR to provide 2 Hi Resolution B&W cameras (FCF BSD B.2.3.5.3) FIR to provide 1 ultra-high frame rate camera (FCF BSD B.2.3.5.3.1.3) FIR to provide white light and white light panel through a window on the EP (FCF BSD B.2.3.5.4.1.1).	YES
Concentration field	Visual images used to measure relative fraction of small spheres (~1 mm diameter) from large spheres (~ 2 mm diameter) at the sidewalls leads of test cell.	*PI to provide camera lens for 25X25 cm FOV*	YES
Velocity field	Record moving boundary velocity to an accuracy of +/- 1% at 1 Hz. Control to +/- 2%. Sphere velocities are on the order of the moving belt velocity, which ranges from 1 to 10 cm/sec.	FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) *PI to provide sheet generator, which interfaces to laser.*	YES
Number, duration of tests	10 to 20 tests; each test lasting 10 to 20 minutes. "Fluids" used are various size metal spheres in air	*PI to provide the ability to accommodate samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f14B:** *Gas-Particle Interactions*	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Each test collects images from: • two 30 fps cameras for ~200 seconds • 10,000 frames from ultra-hi rate camera which will generate ~7 GB/test. Assuming 15 tests, this experiment will generate ~105 GB [~0.8 tera bits] of image data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES
Data acquisition function (non-imaging)	Temperature measured to 1% accuracy and a frequency of 1 Hz. Pressure and humidity measured to 5% accuracy and a frequency of 1 Hz.	*PI to provide temperature, pressure and humidity measurement device in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time " Assuming ISS can download at 3 Mbits/s, time to down-link is 78 hours for all experiment run data.	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

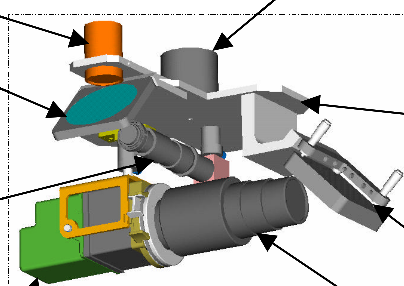
Proposed diagnostics layout

Laser
w/Collimator

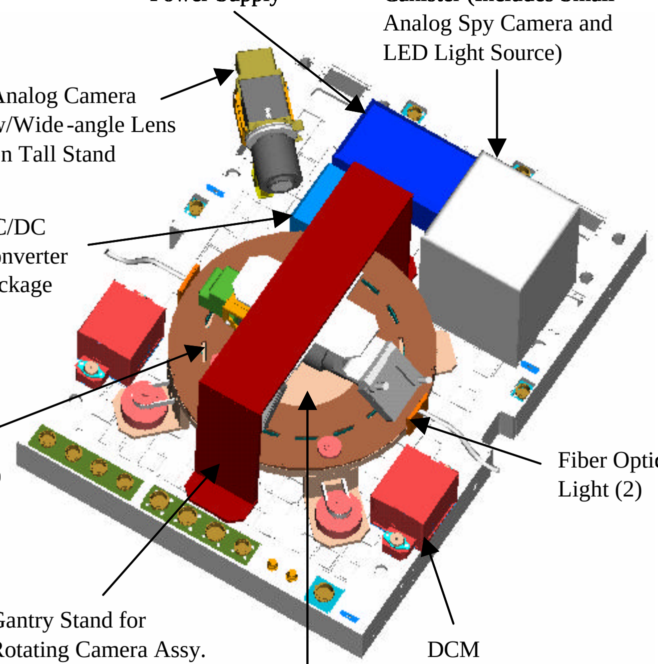
Drive Motor (mounts
to Gantry Stand)



Enlarged View of Rotating Cell
Assy. (Top Cover not shown)
*Test Cell Media (Balls) fill gap
between Inner and Outer Drive Ring



View "A"



See View "A" for
Camera Assembly

Science Requirements Document Summary for

Shear Rheology of Complex Fluids (f15A)

Principal Investigator: Sangani

Experiment Objective:

The general objective is to validate the theory for bubble interactions in a bubbly suspension based on potential flow approximation for spherical high-Reynolds-number bubbles. Want to measure the radial bubble profile in a cylindrical Couette device over various shear rates, volume fractions, and bubble diameters. Results of these measurements will be compared with theoretical predictions to test the averaged equations of motion for bubbly liquids including predictions for the disperse phase pressure and viscosity. The objective is also to conduct a parametric study of the dependence of bubble pressure and viscosity on the shear rate and bubble volume fraction and radius, and to show whether the enhanced viscosity created by the bubbles' fluctuations delays the transition to turbulence.

Experiment Summary:

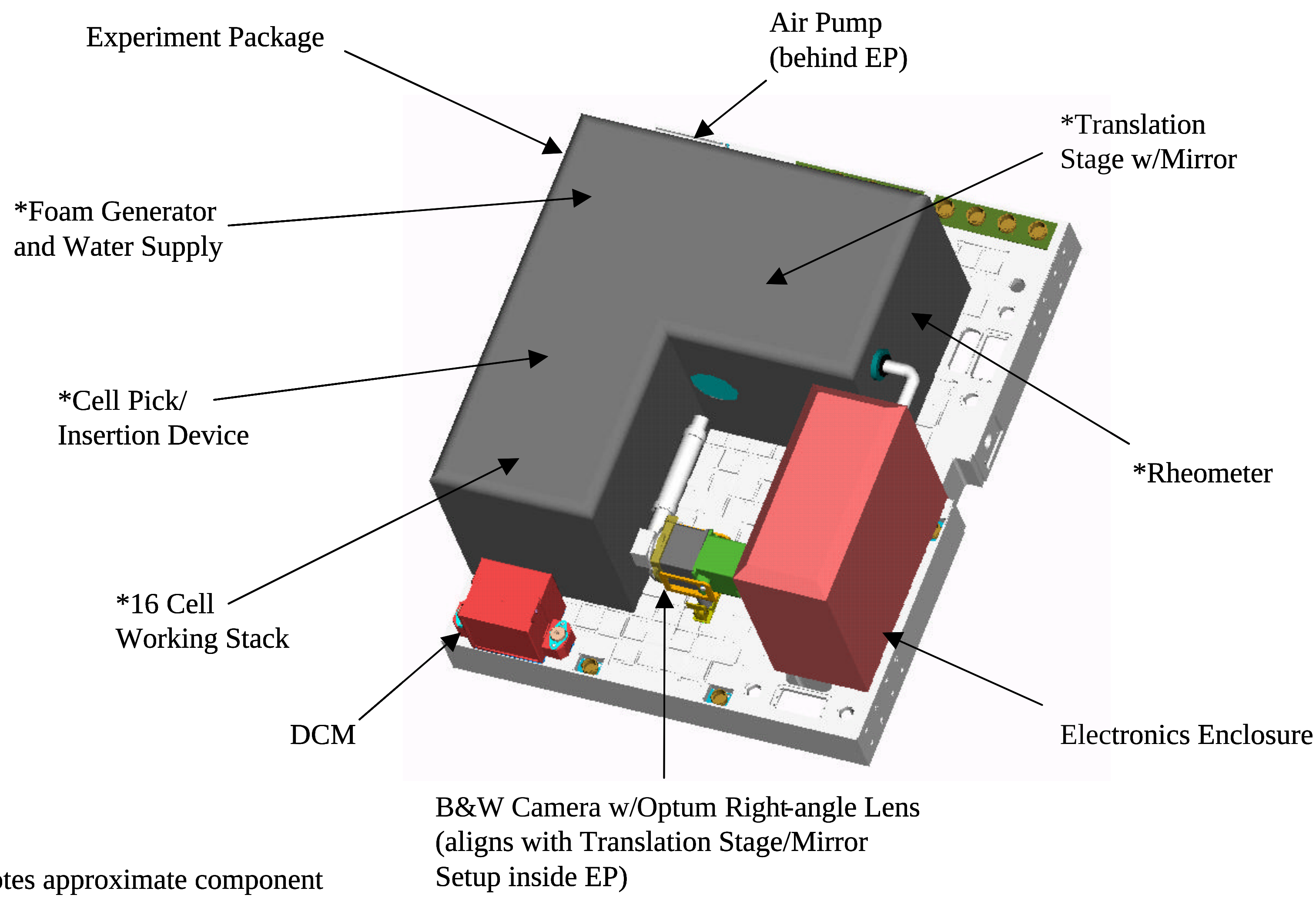
PIs want to make experimental measurements of bubble volume fraction profiles in a Couette device in microgravity. Without buoyancy, the effects of shear induced bubble collision can be isolated In addition, The PIs want to establish relatively high bubble Reynolds numbers and small Weber numbers to achieve potential flow approximation with nearly spherical bubbles. The Couette cell device consists of two concentric cylindrical shells in between which the suspension is contained. The outer shell of the couette rotates to establish the shear flow. The goal is to study the bubble radial distribution in the gap between the shells and to measure the shear stress at the wall. The dispersed phase pressure will resists the centrifugal force which pulls the bubbles toward the inner shell, until steady state is achieved which allows for measurements to be made. PIs want to vary the volume fraction between 0.1 and 0.3 as well as the bubble diameter (1 to 3 mm) and the shear rates for these experiments. To inhibit bubble coalescence, the continuous phase of the suspension is made of a salt solution.

Requirement Types: **Operating Conditions**	**SRD Requirements for f15A:** *Shear Rheology of Complex Fluids*	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions	Overall test container is about 25X75X15 cm = 28 liters	*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 3 \times 10^{-5}$ for DC G for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	Pressure requirement in the EP is: • 1 atmosphere ±0.005 atm during runs • 1 atmosphere ±0.03 atm between runs	*PI to provide pressure control of test cell and measurement device*	YES
Operating Temperature	Temperature requirement in the EP is: • 22 °C ±0.5°C during runs • 22 °C ±2°C between runs	*PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell.*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f15A:** *Shear Rheology of Complex Fluids*	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Size/shape (both general & microscopic) of bubbles near walls and shear strain and shear strain rates, and localized volume fractions within the bubbles.		
Visual Imaging	Framing rate: • 30 fps generally • 30 to 1,000 fps for short periods of time FOV: variable up to 10 bubble diameters Depth of field: 0.2 X diameter of smallest bubble Resolution < 1% of bubble diameter	FIR to provide Hi Resolution B&W camera (FCF BSD B.2.3.5.3) FIR to provide 1 ultra-high frame rate camera (FCF BSD B.2.3.5.3.1.3) FIR to provide white light and white light panel through a window on the EP (FCF BSD B.2.3.5.4.1.1).	YES
Concentration field	Visual images used to measure volume fraction of bubbles		YES
Velocity field	Visual images used to measure bubble velocities; maximum bubble velocities expected to be approximately 600 cm/s.		YES
Number, duration of tests	30 to 50 tests; each test lasting 15 to 30 minutes. Fluid used is aqueous 0.05 molar salt solutions of $MgSO_4$ that must be surfactant free.	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f15A:** *Shear Rheology of Complex Fluids*	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Each test will generate as much as 250 MB [~ 2 giga bits] of imaging data (assuming 1 B&W cameras at 30 fps for 5 seconds and 500 frames from ultra-high rate camera). Therefore, 50 tests will generate ~13 GB [~0.1 tera bits] of image data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES
Data acquisition function (non-imaging)	Temperature in the EP test cell (22 °C ±0.5°C during runs; 22 °C ±2°C between runs); measured with a frequency of 10 Hz Pressure in the EP test cells (1 atmosphere ±0.005 atm during runs; 1 atmosphere ±0.03 atm between runs) ; measured with a frequency of 10 Hz Shear strain, step-strain, shear strain rate and force (wall shear stress); measured with a frequency of 10 Hz	*PI to provide temperature & pressure measurement in the test cell.* *PI to provide rheometer* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time " Assuming ISS can download at 3 Mbits/s, time to down-link is ~10 hours for all image data	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

Proposed diagnostics layout



*Denotes approximate component location inside EP

Science Requirements Document Summary for

Foam Optics and Mechanics (FOAM) (f15B)

Principal Investigator: Durian

Experiment Objective:

The objective of this experiment is to exploit the rheological and multiple light scattering technologies under microgravity conditions in order to understand unusual elastic characteristics of foams in terms of underlying microscopic structures and dynamics. More specifically, how elastic characteristics vanish as the foam melts into a simple liquid will be investigated as a function of varying liquid content percentages and shear strain rates.

Experiment Summary:

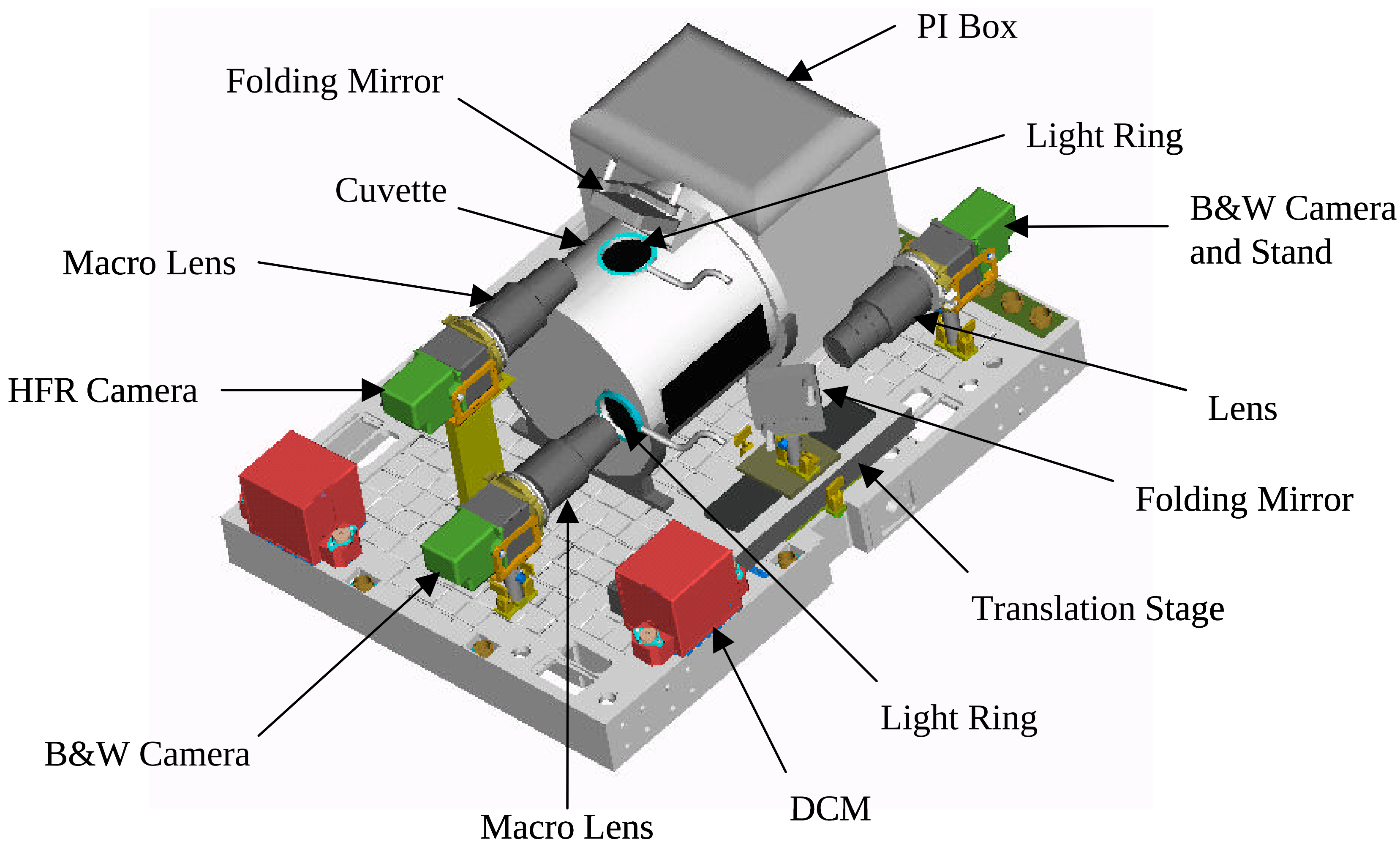
A fluid cell should be constructed to provide for the study of rheological and bubble dynamic characteristics of a bubbly foam. Such a cell should be able to provide for a uniform shear deformation throughout the cell. The experimental apparatus should be able to generate and load the foam into the cell and be able to manage the surface of the foam adequately. Provisions should also be made in the cell design to be able to study a variety of liquids and a variety of bubble sizes. Foams possess vapor, liquid, and solid-like behaviors. A variety of liquids, liquid fractions, and shear rates will be studied. Coarsening will also be a factor in which the foam will be studied at various times after its initial formation.

Requirement Types: **Operating Conditions**	**SRD Requirements for f15B:** *Foam Optics and Mechanics (FOAM)*	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions		*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000.
Acceleration and Vibration	$G/G_0 < 10^{-2}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	Pressure in test cell must be maintained ±0.01 atm (at any pressure near ambient) for all samples tested.	*PI to provide pressure control of test cell*	YES – ambient actively controlled by ISS
Operating Temperature	Temperature of test cell must be maintained ±0.2°C (at any temperature between 20 and 30 °C) for all samples tested.	*PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system Humidity -- Mixture will be saturated water vapor; provisions should be made to prevent excessive evaporation in the test cell	*Air Flow – PI to provide air flow control in the test cell* Humidity: FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide humidity control in the test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f15B:** *Foam Optics and Mechanics (FOAM)*	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest	Size/shape (both general & microscopic) of foam near walls and shear strain and shear strain rates		
Visual Imaging	Framing rate: 30 fps FOV: variable up to 10 bubble diameters (estimated to vary from 100 microns to 5 mm) Depth of field: 0.2 X diameter of smallest bubble (estimated at 20 microns) Resolution < 1% of bubble diameter	FIR to provide Hi Resolution B&W camera (FCF BSD B.2.3.5.3) FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) FIR to provide white light and white light panel through a window on the EP (FCF BSD B.2.3.5.4.1.1).	YES
Number, duration of tests	30 to 50 tests; each test lasting 1,000 to 1,200 minutes (including set up time). Fluids used: Aqueous solutions using 0.8% sodium alpha-olephinsulfonate (AOS) plus either of these: 0.2% dodeconol, or 1% butanol; or 0.2% polyacrylic acid. About 100 ml of liquid total.	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f15B:** *Foam Optics and Mechanics (FOAM)*	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Each test will generate as much as 250 MB [~ 2 giga bits] of imaging data (assuming 1 B&W cameras at 30 fps for 5 seconds and 500 frames from ultra-high rate camera). Therefore, 50 tests will generate ~13 GB [~0.1 tera bits] of image data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES
Data acquisition function (non-imaging)	Temperature in the EP test cell Pressure in the EP test cells Shear strain, shear strain rate and total thrust (i.e stress). Expected stress is between 0.001 and 10000 dynes/cm^2. Angular speeds expected to be between 0.001 and about 100 rpm.	*PI to provide temperature & pressure measurement in the test cell.* *PI to provide rheometer* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time " Assuming ISS can download at 3 Mbits/s, time to down-link is ~10 hours for all image data	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

Proposed diagnostics layout



Science Requirements Document Summary for

LFCA Low Volume Fraction (f16A)

Principal Investigator: Yodh

Experiment Objective:

These experiments will be studying the nucleation and growth of surface crystal structures from colloidal suspensions. The studies will be exclusively focusing on low-volume-fraction binary particle suspensions. Generally, these entropically-driven crystallization experiments will be studying the creation of new and novel colloidal structures of industrial importance (e.g., photonic band-gap crystals). Specifically, the following are of importance in these experiments: the nature of the crystal during its formation (i.e., its size, quality [# of defects], and its structure), the concentrations and size ratios of large/small binary particles, and index of refraction differences between particles and solvents. Of great interest is to study crystal growth on specific surface templates. This promotes crystal growth with a particular structural bias and geometry.

Experiment Summary:

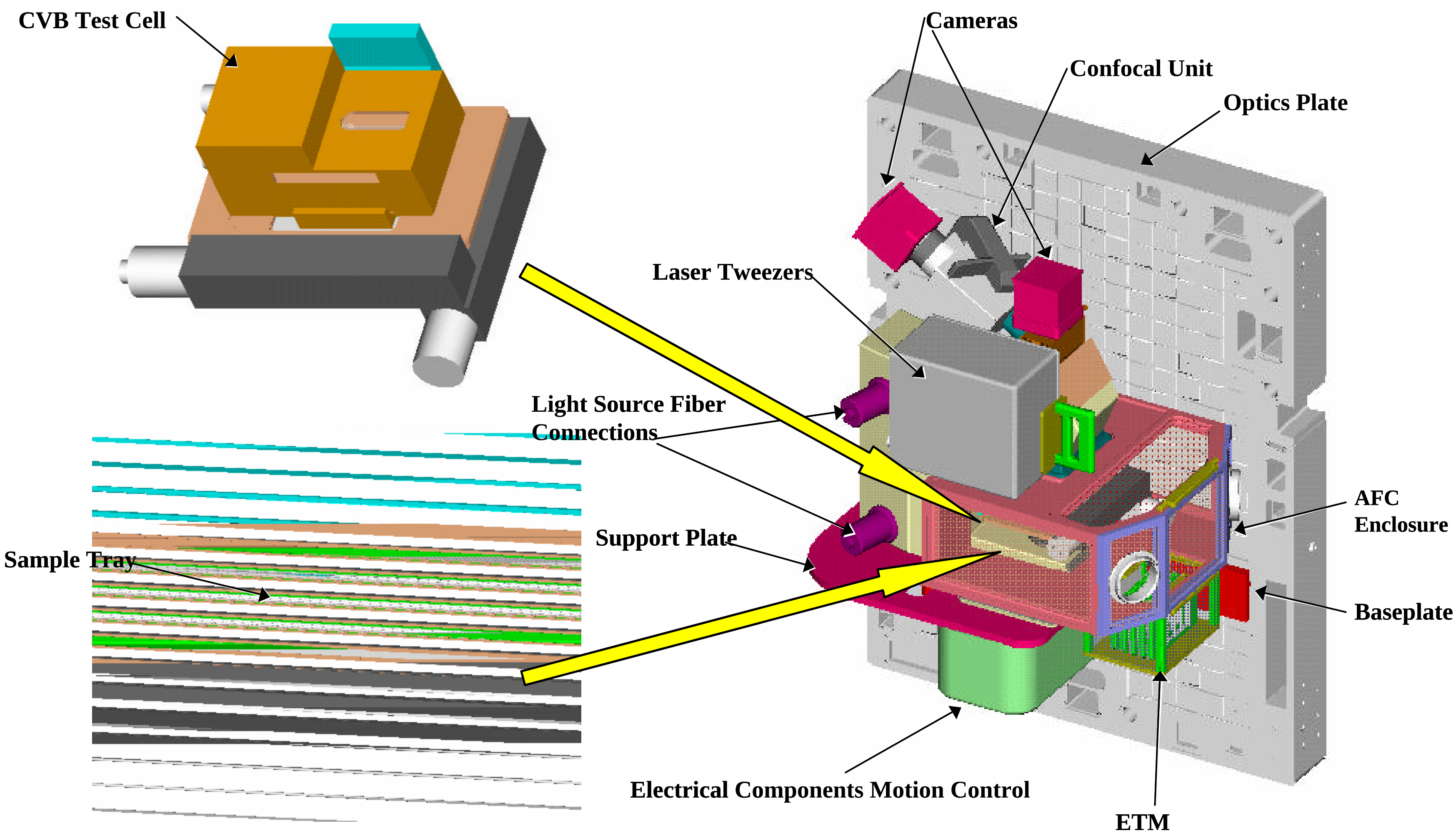
As mentioned above, these experiments focus on the study of low-volume-fraction binary particle suspensions. It will primarily look at crystallization on particular surfaces. The unagglomerated sphere diameters in this binary system are small enough so that thermodynamically driven Brownian motion maintains the suspension. Sphere diameters will be on the order of 500 nm for the “larger” spheres and on the order of 50 nm for the “smaller” spheres. The crystallization or attractive interaction among the larger spheres is brought about by the so-called “depletion” effect. This effect can be explained by the fact that as two large spheres are brought very close together such that the distance between centers is less than the sum of the small and large sphere diameters, then the volume available for the small spheres actually increases. Therefore, the small sphere configurational entropy increases and concomitantly their free energy decreases. The same arguments can be made for the cases where large spheres approach a wall or a corner. The effective attractive forces are very small and the crystals are rather fragile. The crystallization forces are internal from the suspension rather than imposed from the containment forces as is the case for the relatively high volume fraction (i.e., greater than 0.5) experiments of Chaikin and Weitz. However, like the Chaikin and Weitz experiments, similar diagnostics are required (video microscopy and laser light scattering); and small sample cells are envisioned as well. The main control parameters of the experiment are: types of spheres, small and large sphere diameters, small and large sphere volume concentrations, solvent, and for the case of surface templates, template types. The measurements of interest include: visual imaging (normal and micro) of the crystal structure and quality; quantification of the light transmitted through crystal as faction of wavelength and angle of incidence (photonic band-gap determination) using the spectrophotometer; determination of the liquidous curve on a volume fraction plot; direct measurement of the large particle interaction potential (perhaps using laser tweezers); the control of entropic interactions with the use of pre-fabricated templates; and the anneling of the crystals/suspensions (to eliminate defects).

Requirement Types: **Operating Conditions**	**SRD Requirements for f16A:** ***LFCA Low Volume Fraction***	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions		*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000; drawing is the same for all 4 f16 experiments
Acceleration and Vibration	$G/G_0 < 10^{-4}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	Temperature must be controlled to ±1°C in the test cell	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f16A:** ***LFCA Low Volume Fraction***	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest			
Visual Imaging	Framing rate: 30 fps FOV: • 3 X 3 cm for overall view • Variable from 0.1 to 1 mm Resolution: about 0.25 microns to resolve small crystal structures	FIR to provide 2 Hi Resolution B&W cameras and 1 color camera (FCF BSD B.2.3.5.3) FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) FIR to provide white light and white light panel (FCF BSD B.2.3.5.4.1.1). *PI to provide 1064 wavelength Nd: YAG laser and laser tweezers* *PI to provide microscope* *PI to provide confocal microscopy unit*	YES
Number, duration of tests	Experiment duration: 1 hour to 5 days (average 24 hours). Each experiment requires continual periodic monitoring. Fluids used are decalin & tetralin mixtures, optical immersion oil, water. Particles may be ZnS, latex, polystyrene, PMMA, soap micelles.	*PI to provide the ability to accommodate multiple samples.*	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f16A:** ***LFCA Low Volume Fraction***	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Assuming image data is collected for 1 minute/hour at 2 fps, a 24 hour experiment will generate ~9 GB [~ 72 giga bits] of imaging data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES
Data acquisition function (non-imaging)	Temperature measurements ±0.1 °C at a frequency of 1 Hz.	*PI to provide temperature measurement and control in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time " 9 GB of image data can be downlinked in 6.7 hours	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

Proposed diagnostics layout



Science Requirements Document Summary for

Constrained Vapor Bubble (CVB) (f16B)

Principal Investigator: Wayner

Experiment Objective:

Generally this experiment is concerned with the study of a constrained vapor bubble device that focuses on heat pipe – heat transfer mechanisms. Want to understand the heat and mass transport mechanisms that are controlled by interfacial phenomena. Specifically, the objectives are to: determine the overall stability of the device; study the flow characteristics; determine the average heat transfer coefficients in the evaporative and condensing parts of the CVB; and to determine these HTCs as functions of void fraction and heat transfer rates. Also want to evaluate the details of the heat transfer and flow characteristics.

Experiment Summary:

As mentioned above, this experiments studies various heat transfer and flow mechanisms in a constrained vapor bubble heat pipe device. The device itself is a transparent quartz square tube that partially filled with pentane. It is heated at one end (the evaporator end) at a controlled rate and cooled at the other end (the condender end) at the same controlled rate. The vapor is driven from the relatively hot end toward the cooler end and condensed. The liquid film, however, is driven by capillary pressure gradients from the cooler end toward the hot end; thereby feeding in a sense the evaporator. The advantage of a low-g environment is that one achieves a symmetrical film distribution around the tube, which means that larger tubes are possible. This in turn implies that lower viscous stresses are achieved; this was desirable. The larger tube size also facilitates the imaging diagnostics. Experiments in zero-g also greatly simplifies the analysis. Want to test several tubes each containing a bubble of a given size. Three cells will be tested as well as one empty one. For each test, conditions will be kept until steady state conditions are reached. The heating and cooling rates will be equal and will be accurately measured and controlled. A typical test series will increase these rates in a step wise manner; achieving quasi steady state at each step along the way. When the maximum heating is achieved, then the heating will be decreased in a step-wise manner. For each test various measurements will be taken including: film thickness, over all imaging (bubble position measurement), temperature profiles, and heat fluxes (power in, power out), pressure level, area of dry area, and whether or not there are any oscillations in the flow.

Requirement Types: **Operating Conditions**	**SRD Requirements for f16B:** *Constrained Vapor Bubble (CVB)*	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions		*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000; drawing is the same for all 4 f16 experiments
Acceleration and Vibration	$G/G_0 < 10^{-4}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	No control required outside of the test cell Pressure control required within the test cell; expected range from 280 to 1000 Torr. Required accuracy is ± 5 Torr; required resolution ± 1 Torr.	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide pressure control and measurement device*	YES – ambient actively controlled by ISS
Operating Temperature	No control required outside of the test cell Temperature control required within the test cell; center portion of test cell controlled ±5 °C of ambient temperature. Also, experiment requires measurement and control of heat input and output to the cell (up to 1W controllable to ±0.01W). Temperatures within the cell are expected to range from –25 to +225 °C.	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f16B:** *Constrained Vapor Bubble (CVB)*	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest			
Visual Imaging	Framing rate: 30 fps FOV: • 3 X 3 cm for overall view • Variable from 0.1 to 1 mm Resolution: about 0.25 microns to resolve small crystal structures	FIR to provide 2 Hi Resolution B&W cameras and 1 color camera (FCF BSD B.2.3.5.3) FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) FIR to provide white light and white light panel (FCF BSD B.2.3.5.4.1.1). *PI to provide 1064 wavelength Nd: YAG laser and laser tweezers* *PI to provide microscope* *PI to provide confocal microscopy unit*	YES
Temperature field	Temperature profiles are to be measured along the axis of the cell. This includes measurements in the heater, cooler, and "isothermal" sections. Temperatures are expected to range from –25 to +225 °C. Measurement accuracy will be ±0.1 °C.	*PI to provide (non-optical) measurement devices to measure temperature profile of test cell*	
Number, duration of tests	8 tests (4 cells; heating and cooling procedure for each cell); each test lasting 5 minutes. Fluids used: pentane	*PI to provide the ability to accommodate multiple samples.*	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f16B:** *Constrained Vapor Bubble (CVB)*	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Assuming image data is collected from 2 cameras for 5 minutes at 30 fps, each test will generate ~28 GB [~ 230 giga bits] of imaging data. Eight tests will generate 224 GB [1.8 terra bits] of imaging data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature measurements ±0.1 °C Pressure ± 5 Torr	*PI to provide pressure and temperature measurement device in the test cell* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time " 28 GB of image data from each test can be downlinked in 21 hours	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	Given ISS limitations on energy and the rate of data downlink, compliance will require data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.

Science Requirements Document Summary for

Dynamics of Hard Sphere Colloids (f16C)

Principal Investigator: Chakin

Experiment Objective:

These experiments will be studying nucleation, growth, rheological properties and morphology of crystal structures in the context of a hard sphere colloidal suspension. Create novel structures and study their dynamics of formation and physical properties as well as try to define various transitions. Specifically, the objective of the experiment is to determine kinetic and equilibrium structures for suspension at various volume fractions. Want to be able to identify the various liquid, crystalline, and glass states and their transitions regions. Also want to study how hard sphere colloidal suspensions respond to applied fields that force the particles into non-equilibrium conditions; and to study the effects of polydispersity, micro-rheology, and dendritic instabilities. For the Cafe experiments specifically, they will be studying the nucleation and growth behavior kinetics near liquid-glass transition; structure rheology of the equilibrated crystals; and the coarsening of the crystals over time.

Experiment Summary:

Hard spheres simulate liquid-like and solid-like characteristics as seen in normal materials (fluids and solids). They show repulsive forces in liquid-solid transitions and attractive forces in gas-liquid transitions. There are various arrangements depending on the volume fraction of particles in the host liquid. From liquid to liquid-solid to crystal-glass type structures. The problem in a one-g environment is that the particles settle and the resultant crystals are very small (100 microns). In microgravity they can get to on the order of mm's. Once the solution is mixed, the spheres slowly begin to nucleate throughout the volume. Each nucleation site begins to grow as more site are nucleated. Eventually they begin to aggregate and continue to grow. With this coarsening process the solution eventually reaches equilibrium and can be characterized in a liquid, crystalline or glassy state. Want to test, under equilibrium, for the effects of polydispersity, micro-rheology, viscoelasticity; and under non-equilibrium, for non-linear rheology, melting processes, dendritic instabilities. In addition, want to be able to control the nucleation and growth processes. Such processes and phenomena will be investigated with such optical diagnostics as low and high angle light scattering, Bragg scattering, video microscopy, dynamic light scattering, and laser tweezers. The long range order is tested by the various light scattering methods. The microscopic order is tested for by microscopy. The concept for the experiments will be to have numerous colloidal samples to be tested. Samples sizes are not large (on the order of 0.1 cc). Various optical diagnostics are envisioned for these experiments and are given below.

Requirement Types: **Operating Conditions**	**SRD Requirements for f16C:** *Dynamics of Hard Sphere Colloids*	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions		*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000; drawing is the same for all 4 f16 experiments
Acceleration and Vibration	$G/G_0 < 10^{-4}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	ambient; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test cells must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f16C:** *Dynamics of Hard Sphere Colloids*	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest			
Visual Imaging	Framing rate: 30 fps FOV: • 3 X 3 cm for overall view • Variable from 0.1 to 1 mm Resolution: about 0.25 microns to resolve small crystal structures	FIR to provide 2 Hi Resolution B&W cameras and 1 color camera (FCF BSD B.2.3.5.3) FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) FIR to provide white light and white light panel (FCF BSD B.2.3.5.4.1.1). *PI to provide 1064 wavelength Nd: YAG laser and laser tweezers* *PI to provide microscope* *PI to provide confocal microscopy unit*	YES
Number, duration of tests	About 200 test cells; total test time on all samples of 118 days (2,832 hours) Fluids used: Hard spheres of PMMA are in a host liquid, a combination of decalin and tetralin chosen to index match the particles. The volume fraction of the spheres in the various cells will range between 0.47 and 0.64. Sphere diameters are 0.65 to 1 microns and controllable to 5% polydispersity	*PI to provide the ability to accommodate multiple samples.*	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f16C:** *Dynamics of Hard Sphere Colloids*	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Assuming image data is collected for 1 minute/hour at 2 fps, a 24 hour experiment will generate ~9 GB [~ 72 giga bits] of imaging data. In 118 days, more than 1TB [~ 8 tera bits]of imaging data could be collected.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature	*PI to provide temperature measurement and control in the test cell.* FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time " 9 GB/day of image data can be downlinked in 6.7 hours	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

Science Requirements Document Summary for

Colloid Physics (f16D)

Principal Investigator: Weitz

Experiment Objective:

Similarly to the Chaikin-Phase-2 work, these experiments will be studying nucleation, growth, morphology and coarsening of crystal structures as well as rheological structural properties. However, instead of hard spheres, there are three general groups or classes of samples: binary alloys (highly ordered), polymer mixtures, and fractal aggregates (highly disordered). With respect to binary alloys want to study morphology/ structures, nucleation, growth, and coarsening, and the phase diagrams. For the polymer mixtures want to be able to have controllable forces, for the study of nucleation, growth, and coarsening. For fractal aggregates want to study large scale invariant structures and their visco-elastic mechanical properties.

Experiment Summary:

In a particle suspension in one-g, the effects of sedimentation and convection interferes with the nucleation/growth/coarsening processes that occur. It thereby limits the size of the ultimate crystals and particles achieved in the solution. As mentioned above, these experiments, study many of the same types of physical phenomena as the Chaikin type experiments and use many of the same diagnostic techniques. The particles and solutions used here are different and are grouped into three categories: colloid polymers, fractal aggregates, and binary alloys. The colloid polymers are a gel like state. The fractal aggregates experiments primarily study the mechanical structural behavior of the aggregate.

As before, the particles simulate liquid-like and solid-like characteristics as seen in normal materials (fluids and solids). They show repulsive forces in liquid-solid transitions and attractive forces in gas-liquid transitions. There are various arrangements depending on the volume fraction of particles in the host liquid. From liquid to liquid-solid to crystal-glass type structures. The problem in a one-g environment is that the particles settle and the resultant crystals are very small (100 microns). In microgravity they can get to mm's. Once the solution is mixed the spheres slowly begin to nucleate throughout the volume. Each nucleation site begins to grow as more site are nucleated. Eventually they begin to aggregate and continue to grow. With this coarsening process the solution eventually reaches equilibrium. Want to test, under equilibrium, for the effects of polydispersity, micro-rheology, viscoelasticity; and under non-equilibrium, for non-linear rheology, melting processes, dendritic instabilities. In addition, want to be able to control the nucleation and growth processes. Such processes and phenomena will be investigated with such optical diagnostics as low and high angle light scattering, Bragg scattering, video microscopy, dynamic light scattering, and laser tweezers. The long range order is tested by the various light scattering methods. The microscopic order is tested for by microscopy. The concept for the experiments will be to have numerous colloidal samples to be tested. Samples sizes are not large. Various optical diagnostics are envisioned for these experiments and are given below.

Requirement Types: **Operating Conditions**	**SRD Requirements for f16D:** *Colloid Physics*	**FCF Capabilities**	**Compliance Comments**
Test Section Dimensions		*PI hardware installed as an integrated package* on the FIR optics plate. *PI to provide two levels of containment.*	YES – see attached ProE drawing developed from the layout exercise in July/August 2000; drawing is the same for all 4 f16 experiments
Acceleration and Vibration	$G/G_0 < 10^{-4}$ for DC G-levels for G-jitter frequencies – no data	FIR to provide active ARIS. (FCF BSD 5.1.3)	YES – SAMS data required for verification.
Operating Pressure	1.0 atmosphere; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10)	YES – actively controlled by ISS
Operating Temperature	ambient; no control required	FIR to provide Atmospheric Monitoring Assembly (FCF BSD B.2.3.10) *PI to provide thermal control of test cell*	YES -- Water cooling available to PI NOTE: ISS cooling water varies from 61 to 65 F due to orbital variations
Other Experiment Conditions	Air flow -- Test Container/Test Cell must be free from air circulation disturbances caused by the air thermal control system	*Air Flow – PI to provide air flow control in the test cell*	YES

Requirement Types: **Systems and Measurements**	**SRD Requirements for f16D:** *Colloid Physics*	**FCF Capabilities**	**Compliance Comments**
Phenomenon of interest			
Visual Imaging	Framing rate: 30 fps FOV: • 3 X 3 cm for overall view • Variable from 0.1 to 1 mm Resolution: about 0.25 microns to resolve small crystal structures	FIR to provide 2 Hi Resolution B&W cameras and 1 color camera (FCF BSD B.2.3.5.3) FIR to provide Nd: YAG laser (FCF BSD B.2.3.5.4.1.2) FIR to provide white light and white light panel (FCF BSD B.2.3.5.4.1.1). *PI to provide 1064 wavelength Nd: YAG laser and laser tweezers* *PI to provide microscope* *PI to provide confocal microscopy unit*	YES
Number, duration of tests	About 2000 test samples; total test time on all samples of 118 days (2,832 hours) Particles are in a host liquid, a combination of decalin and tetralin chosen to index match particles. For the fractal aggregate experiments particles are polystyrene, silica, and gold particles. For the binary alloy experiments, particles are PMMA-PMMA, PMMA-silica, and PMMA-metal combinations. For the Colloidal polymer experiments particles are PMMA, polystyrene, and silica-polystyrene particles. Sphere diameters will range from 10 nm to 5 microns.	*PI to provide the ability to accommodate multiple samples*.	YES

Requirement Types: **Data Acquisition and Management**	**SRD Requirements for f16D:** *Colloid Physics*	**FCF Capabilities**	**Compliance Comments**
Data Time Resolution Time resolution Time synchronization	All data time-tagged to reference other data. All data time correlated to 0.001 s for experimental events and 1 s for external events.	FIR to provide (FCF BSD B.2.3.6.3)	YES
Data storage and processing	Assume data collection and storage is similar to f16c. Assuming image data is collected for 1 minute/hour at 2 fps, a 24 hour experiment will generate ~9 GB [~ 72 giga bits] of imaging data.	FIR interface to IPSU (FCF BSD 5.2.5) and FSAP (FCF BSD B.2.3.7)	YES – However, compliance will require additional PI or FIR provided data storage devices AND/OR a combination of data compression, data cropping, real-time data reduction and/or selective intervals of data collection during tests.
Data acquisition function (non-imaging)	Temperature Rheology	*PI to provide temperature measurement and control in the test cell*. PI to provide devices for measuring viscosity and elasticity. FIR provided FSAP can monitor and record PI specific signals as required (FCF BSD B2.3.7)	YES
Up/Down link	"Real time " 9 GB of image data can be downlinked in 6.7 hours	IOP/ISS HRDL (FCF BSD 3.0, 3.3, 5.25)	YES

Appendix C – FIR Typical On-orbit Operations Scenario

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There are numerous scenarios that can be analyzed based on maximizing or using limits of certain resource variables. The following analysis demonstrates resource usage and downlink operations, and maximizing daily downlink and science operations during one micro-gravity period.

1 DATA PROVISIONS

The following sections discuss the three methods to store or transfer data.

1.1 DOWN LINKING

The FIR has the following data downlink resource provisions:

- FCF-SPC-0001, FCF System Specification Paragraph 3.2.2.3
  - Downlink rate of 6 Mb/s
  - Downlink daily volume of 20 GB/day for FCF

    (Flight segment plus installed PI specific equipment systems data)

- SSP 57117, Payload Integration Agreement for the FCF, Table 3
  - Downlink annual volume of 41.1 Tb/year for FIR

1.2 STORAGE ON HARD DRIVES

FIR will have the following data storage available on IOP and IPSU hard drives:

- 2 removable 73 GB hard drives in the IOP. A minimum total of 73GB will be available for PI storage.
- 2 non-removable 18 GB hard drives in each of 2 IPSUs. A minimum total of 30 GB available to the PI in each IPSU.

Removable hard drives will be used to transfer data to ground or can be used as temporary storage until down linked following a science (micro-gravity) period. Based on a PI's data collection needs, trade-off of down linking versus the hard drive swapping resource usage of up mass, down mass, up volume, down volume, and crew time.

1.3 ISS VIDEO INTERFACE

ISS provides SVHS video recording via the rack CVIT interface capable of recording 2 hours of continuous video.

2 ASSUME

2.1 THROUGHPUT

5 PIs per year – each PI sharing equal time.

2.2 MICRO-GRAVITY

180 micro-gravity days per year, in 30 day blocks – equating to 6 micro-gravity periods. Practically, this should provide each of the 5 PIs a 30 day micro-gravity period.

Due to limited micro gravity periods it assumed that CIR will be operating for half the time and FIR will be operating for half the time during the micro-gravity periods. FIR conducts science operations for 12 hours per day during micro-gravity periods. Any FIR reconfiguration, sample change-out, or hard drives swapping for FIR will happen during CIR's 12-hour science operation period.

2.3 DATA

- FIR data is minimal in comparison to bulk PI data.
- AOS/LOS is approximately 60%.
- Based on throughput assumptions, each PI will receive 1/5 of the total annual data allocation, 8.22 Tb. (SSP 57117). This analysis will show that this is not the constraining requirement.
- Data resource allocations are equivalent to FCF-SPEC-0001, paragraph 3.2.2.3, Table III.
- FIR daily downlink volume is 10GB, one half of the 20GB FCF provision from FCF-SPEC-0001.

2.4 ENERGY

- Approximately 400 W of power is required during down linking periods.
- Each PI is allocated 900 kW-Hrs of energy (9000 kW-Hrs/ 10 Fluids-Combustion PIs).
- For conservatism, the rack and PI use approximately 2000 W of power during science operations.

3 ANALYSIS

During the 30-day micro-gravity period, the PI maximizes its daily downlink allocation (10 GB). Therefore the PI downlinks 300 GB total or 29% of the 8.22 Tb allocation during the micro-gravity period. The PI downlinks for 6.3 hours each day and uses approximately 75.6kW-Hrs of total power for the micro-gravity period for down linking or 8% of the PI allocated energy (900kW-hrs). Based on the 12hr/day science operation and time spent down linking, FIR will conduct science operations for 5.7 hours per day. Over the micro-gravity period, 342kW-hrs will be used to conduct science or approximately 38% of the PI energy allocation. Using this conservative approach for one micro-gravity period: a total of approximately 46% of the PI energy allocation will be used, 300GB of data will be down linked, and 189 hours of science will be accomplished. 54% of the energy allocation will be available to complete additional science.

If the PI needs to collect more than 10GB of data per day but never accumulates more than 73GB during the micro-gravity period, this data can be saved on the IOP hard drives and down-linked following the micro-gravity period. If the PI accumulates more than 73GB of data, an IOP hard drive will have to be swapped. Depending on the PI's power usage during the micro-gravity period, the PI can make the decision to either downlink data from swapped hard drives during non-micro-gravity periods or to return the filled hard drives to ground. This trade-off will be made based on the trade-off between expending additional crew time versus mass/volume.

From figure F12, an average experiment requires 384 hours of operation. The above scenario provides 189 hours of science time to the PI. With energy and downlink resources still available, science could be completed during a second micro-gravity period, an extended micro-gravity period (30 days is thought to be the minimum period), or science that does not require the micro-gravity period could be completed outside of the micro-gravity period.

Appendix D – FCF Acronym List

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Appendix D – FCF Acronym List

AC	Assembly Complete
ARIS	Active Rack Isolation System
ATCS	Air Thermal Control System
ATCU	Air Thermal Control Unit
BSD	Baseline System Description
C&C	Command and Control
C&DH	Command and Data Handling
CAM	Centrifuge Accommodations Module
CBT	Computer Based Training
CDMS	Command and Data Management Subsystem
CEM	Combustion Experiment Management
CIDS	Critical Item Development Specification
CIR	Combustion Integrated Rack
CM	Combustion Module (in reference to Combustion Module-I)
CM	*Compliance Matrix*
COR	Communication Outage Recorder
COUP	Consolidated Operations and Utilization Plan
CP	Chamber Package
CTB	Collapsible Transfer Bags
DARTFire	Diffusing & Radiative Transport Controlled Fire
DCE	Droplet Combustion Experiment
E&TS	Engineering & Technical Services Directorate
ECS	Environmental Control System
EHS	Enhanced HOSC System
ELV	Expendable Launch Vehicle
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMCS	Enhanced Mission Communications System
EMI	Electromagnetic Interference
EMS	Experiment Mounting Structure
EP	Experiment Package
EPCU	Electrical Power Control Unit
EPS	Electrical Power System
ESP	Electronic Support Package
EVA	Extravehicular Activity
EVP	Exhaust Vent Package
EWT	Embedded Web Technology
FCB	Functional Cargo Block
FCF	Fluids and Combustion Facility
FCU	FOMA Control Unit
FDSS	Fire Detection and Suppression System
FEA	Fluids Experiment Assembly
FIR	Fluids Integrated Rack

Appendix D – FCF Acronym List

FLAP	Facility Laptop
FOMA	Fuel/Oxidizer Management Assembly
FRBP	Fluids Rotating Bench Package
FSAP	Fluids Science Avionics Package
GC	Gas Chromatograph
GDP	Gas Delivery Package
GIS	Gas Interface System
GIU	Ground Integration Unit
GPVP	Generic Payload Verification Plan
GRC	Glenn Research Center
GSE	Ground Support Equipment
GUI	Graphical User Interfaces
HFR	High Frame-rate
HiBMs	High Bit Depth/Multispectral
HOSC	Huntsville Operations Support Center
HR	High-resolution
HRDL	High Rate Data Link
HRFM	High Rate Frame Multiplexer
HRL	High Rate Link
ICD	Interface Control Document
IDD	Interface Definition Document
IDRD	Increment Definition Requirements Document
IOP	Input/Output Processor
IPMM	Integrated Payload Mission Model
IPP	Image Processing Package IPP
IPSU	Image Processing and Storage Units
IRD	Interface Requirements Document
IRR	Interface Resource Ring
ISPR	International Standard Payload Rack
ISS	International Space Station
ISSP	International Space Station Program
ISSPO	International Space Station Payloads Office
ISWG	Increment Science Working Group
ITCS	Internal Thermal Control System
ITCS	ISS Thermal Control System
JSC	Johnson Space Center
LASX	US Lab ISPR Locations (Starboard)
LLL	Low Light Level
LSA	Logistics Support Analysis
MDM	Mutiplexer/Demultiplexer
MER	Mission Evaluation Request
MIT	Mission Integration Team
MPLM	Mini-Pressurized Logistics Module
MRDL	Medium Rate Data Link
MRL	Moderate Rate Link
MRPO	Microgravity Research Program Office
MSAD	Microgravity Science and Applications Division

MSD	Microgravity Sciences Division
MSFC	Marshall Space Flight Center
MTA	Maintenance Task Analysis
MTL	Moderate Temperature Loop
NISN	NASA Integrated Services Network
NRA	NASA Research Announcement
NTSC	National Television System Committee, of the Electronics Industries Association
ORU	Orbital Replacement Unit
OSE&MA	Office of Safety, Environmental and Mission Assurance
OSTP	Onboard Short Term Plan
OZ2	ISS PO Mission Integration and Planning
OZ3	ISS PO Hardware and Software Engineering Integration
PCS	Physics Of Colloids in Space
PDC	Payload Development Center
PDR	*Preliminary Design Review*
PDSS	Payload Data Services Systems
PEHG	Payload Ethernet Hub Gateway
PFE	Portable Fire Extinguisher
PhaSE	Physics of Colloids in Space
PI	Principal Investigator
PIA	Payload Integration Agreement
PIDS	Prime Item Development Specification
PIV	Particle Image Velocimetry
PO	Payloads Office/Project Office
POIC	Payload Operations and Integration Center
PP	*Project Plan*
PPS	Payload Planning System
PPWG	Payload Planning Working Group
PRCU	Payload Rack Checkout Unit
PSF	Power Systems Facility
PSRP	Payload Safety Review Panel
PTC	Payload Training Center
PTCS	Payload Test and Checkout System
PU	4-41 Drawer
PUP	Partner Utilization Plan
PVP	Payload Verification Plan
QA	Quality Assurance
QD	Quick Disconnect
R&M	Reliability and Maintainability
RAID	Redundant Array of Independent Disks
RF	Risk Factor
RFCA	Rack Flow Control Assembly
RHA	Rack Handling Adapter
RIP	Rack Interface Panel
RMO	Research Management Office
RMSA	Rack Maintenance Switch Assembly
RSP	Resupply Stowage Platform

RSR	Resupply Stowage Rack
RVE	Equivalent to 1m^3
SAL	Spread Across Liquids
SAMS	Space Acceleration Measurement System
SAR	Shared Accommodations Rack
SARGE	Standard Assurance Requirements and Guidelines for Experiments
SBC	Single Board Computer
SDP	Safety Data Package
SDPSP	Shared Data Post-Processing/Storage Package
SEIRD	Support Equipment Item Requirements and Description
SOS	Science Operations Site
SRD	Science *Requirements Documents*
SRED	Science Requirements Envelope Document
SSCC	Space Station Control Center
SSCE	Solid Surface Combustion Experiment
SSPF	Space Station Processing Facility
STDCE	Surface Tension Driven Convection Experiment
STEP	Suitcase Test Environment for Payloads
STP	Short-term Plan
STS	Space Transportation System
TBS	Turbulent Gas-Jet Diffusion Flames Experiment
TEC	Thermo Electric Coolers
TGDF	Turbulent Gas-Jet Diffusion Flames
TReK	Telescience Resource Kit
TSC	Telescience Support Center
UIP	Utility Interface Panel
UML	Universal Mounting Location
US Lab	United States Laboratory Module
VES	Vacuum Exhaust System
VRS	Vacuum Resource Service
VRS	Vacuum Resource System
WIP	Water Interface Panel
WTCS	Water Thermal Control System
ZSR	Zero-G Stowage Rack